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DESCRIPTION OF THE U. S. FLEET COLLIER *JUPITER*.

BY LIEUTENANT S. M. ROBINSON, U. S. NAVY, MEMBER.

The *Jupiter* was authorized by Naval Appropriation Act of May 13, 1908, at a limit of cost of $1,800,000.00. The Secretary of the Navy designated the Mare Island Navy Yard as the building yard for the collier provided by the said Naval Act, "to be built in such Government yard on the Pacific Coast as the Secretary of the Navy shall direct." The limit of cost was decreased to $900,000.00 in Naval Appropriation Act of March 3, 1909; subsequently increased to $1,000,000.00 in Naval Appropriation Act of June 24, 1910; subsequently increased to $1,200,000.00 (exclusive of indirect charges) in Naval Appropriation Act of March 4, 1911; the total cost of building the vessel (including indirect charges, but excluding leave, holiday and disability) was $1,271,986.00. The keel was laid October 18, 1911; the vessel was launched August 25, 1912, and went into commission April 7, 1913. The vessel

was built in conformity with the rules of the American Bureau of Shipping.

The ship is of the twin-screw, single-deck type. She was designed for a speed of 14 knots, developing 5,500 S.H.P. with a load displacement of 19,230 tons at a draught of 27 feet 6 inches.

The complement is Navy, and consists of eleven officers and 148 men; of these fifty-five are of the seaman branch, ten in the artificer branch, fifty-nine in the engineer's force, fifteen in the commissary and messman branches, and nine in the special branch.

The general dimensions of the ship are as follows:

Length over all, feet and inches	542–02½
between perpendiculars, feet and inches	520–00
on L.W.L., feet and inches	520–00
Beam, extreme, feet and inches	65–02⅛
moulded, feet and inches	65–00
Draught, mean designed, feet and inches	27–06
Displacement, on designed draught, in tons	19,230
per inch on L.W.L., in tons	64.75
Area in square feet midship section, moulded	1,655
L.W.L. plane	27,140
wetted surface at 27 feet 6 inches draught	27,750
C.B. above bottom of keel, feet and inches	14–05⅛
C.B. abaft of midship section, feet and inches	2–02¾
Transverse metacenter above C.B., feet and inches	12–11¼
Longitudinal metacenter above C.B., feet and inches	624–06⅞
Coefficient of fineness, block	.7215
midship section	.9783
L.W.L. plane	.7954
cylindrical	.7375

HULL AND COMPARTMENTS.

The ship has four decks forward and five aft, the forecastle and poop each being one deck higher than the upper deck. Amidships in the cargo space there is but one deck. There are nine watertight, five oiltight and two non-watertight 'thwartship bulkheads. All decks are of steel except the forecastle, poop and superstructure decks, which are wood with

stringer and tie plates of steel. Steel bulwarks four feet high are built in the waist along the upper deck.

The crew's space consists of the upper and berth decks aft, and there is spare berthing space forward on the same decks. The space aft is fitted with stationary bunks and lockers for the entire crew. The chief petty officers' space is on the port side of the upper deck at the after end of the ship; the sickbay is in a corresponding position on the starboard side. The crew's washrooms are on the starboard side of the upper deck aft, the seamen's being the after one, and the firemen's the forward one, the latter being near the exit from the starboard uptake. The officers' staterooms and mess rooms are on the poop deck.

The storerooms are on the lower deck aft and on the lower and berth decks forward. The paint and oil rooms are on the upper deck forward.

The pump room for handling cargo oil is forward and extends from the forecastle deck to the top of the forward peak tank; the chain locker is forward of the pump room and access is had to it from the pump room.

There are three peak tanks, one forward and two aft.

There are thirteen cargo holds. Holds 1, 2, 3 and 4 are under the forecastle and are for oil only; holds 5, 6, 7, 8, 9, 10, 11, 12 and 13 are between the forecastle and poop in the waist of the ship; of these, 5, 6, 7 and 8 are for either oil or coal. The holds that may be used for oil are in pairs, one on each side of the ship and divided by a fore-and-aft bulkhead. The holds that are used for coal only extend the width of the ship and are of the self-trimming type. There is a cofferdam between hold 9 and the two oil holds 7 and 8 just forward of it. Holds 1, 2, 3 and 4 are fitted with a large expansion trunk which extends up to the forecastle deck. Holds 5, 6, 7 and 8 are covered by 12-foot 6-inch × 14-foot 0-inch hatches. Holds 9, 10, 11, 12 and 13 are each covered by two 12-foot 6-inch × 32-foot 0-inch hatches.

There are three coal bunkers located abaft No. 13 cargo

hold. Number 1 bunker extends from the inner bottom to the poop deck at the forward end, and to the superstructure deck at the after end, the two ends being connected into one bunker over the boilers; the after end of the bunker is divided into two parts by the donkey-boiler space; there are two hatches at each end of the bunker. Nos. 2 and 3 bunkers are small reserve bunkers situated on each side of the engine-room space, and are filled through trunks from four scuttles on the poop deck. These bunkers connect with the main bunker and do not extend below the level of the floor over the boilers. The main bunker has three feeding doors in the forward end of the fireroom and two in the after end.

There are fifteen double bottoms in the ship. Nos. 1, 2, 3 and 4 are under oil holds 5, 6, 7 and 8, and are oiltight, being used for cargo space when these holds are used for oil; they are not to be used for ballast purposes. No. 5 double bottom is under the cofferdam. Nos. 6, 7, 8, 9, 10 and 11 double bottoms are under the coal holds and are used for ballast purposes; they extend the full width of the ship. Nos. 12, 13, 14 and 15 are used for reserve feed purposes and are in pairs divided by a fore-and-aft bulkhead.

There are two fresh-water tanks in the ice-machine room, which is just abaft the engine room. These supply a gravity tank situated on the after end of the superstructure deck.

There are twelve topside ballast tanks, six on each side of the ship, all of them being in the waist.

The work shop is situated on the upper deck at the top of the engine-room hatch. The following machine tools have been authorized for it, but have not yet been supplied:

1 gap lathe;
1 engine screw-cutting lathe;
1 sensitive drill;
1 drill press;
1 shaper;
1 emery grinder;
1 work bench.

At the after end of the forecastle there are located a flying bridge and a lower bridge. On the flying bridge are located the following:

Chart board;
Steering wheel;
Compass;
2 Pelorus stands;
Double-faced engine-room telegraph;
2 Voice tubes;
Telephotus for ardois;
Docking telegraph;
Whistle and siren pulls.

The lower bridge has an emergency cabin and toilet on the starboard side and a chart house on the port side. It also has the following:

Wheel;
Compass;
Double-faced engine-room telegraph;
3 Voice tubes;
Telephone;
Steering telegraph;
Tell-tale board for running lights;
Aneroid;
Whistle and siren pulls.

On the after end of the superstructure deck there is a wheel, docking telegraph and voice tube.

The following table shows the capacities of the various tanks, holds, bunkers, etc.:

Coal Bunkers.	Tons.
No. 1	2,079
No. 2	82
No. 3	80
Total	2,241

Peak Tanks.	Gallons.	Tons.
Forward	76,262	291
No. 1 after	103,410	395
No. 2 after	37,490	143
Total	217,162	829

Fresh-water Tanks.	Gallons.	Tons.
Ship's tanks (2)	5,334	19.8
Gravity tank	268	1.0
D.B. No. 12	22,435	83.0
D.B. No. 13	22,435	83.0
D.B. No. 14	32,055	119.0
D.B. No. 15	32,055	119.0
Total	114,582	424.8

Oil Holds.	Gallons.	Tons.
No. 1	87,744	293.0
No. 2	87,156	291.0
No. 3	115,074	385.0
No. 4	115,643	387.0
Total	405,617	1,356.0
No. 5	136,530	456.0
No. 6	135,663	453.0
No. 7	143,777	481.0
No. 8	144,678	484.0
(These capacities include double bottoms 1, 2, 3 and 4.)		
Grand total of oil holds	966,265	3,230.0

Double Bottoms.	Gallons (S.W.).	Tons.
No. 5	3,456	13.0
No. 6	58,251	223.0
No. 7	68,723	263.0
No. 8	68,723	263.0
No. 9	68,723	263.0
No. 10	65,319	250.0
No. 11	50,004	191.0
Totals	383,199	1,466.0

Coal Holds.	Tons.
No. 5	375.0
No. 6	364.0
No. 7	386.0
No. 8	396.0
Total (5–8)	1,521.0

Coal Holds.	Tons.
No. 9	1,910.0
No. 10	2,064.0
No. 11	2,020.0
No. 12	1,995.0
No. 13	1,867.0
Total (9–13)	9,856.0

Grand total (43 cubic feet equal one ton) 11,377.0

This gives a cargo capacity of 966,265 gallons of oil and 9,856 tons of coal, or 405,617 gallons of oil and 11,377 tons of coal.

Topside Ballast Tanks.	Gallons (S.W.).	Tons.
No. 1	25,900	98.9
No. 2	25,900	98.9
No. 3	38,450	147.0
No. 4	38,450	147.0
No. 5	43,000	164.2
No. 6	43,000	164.2
No. 7	43,450	165.8
No. 8	43,450	165.8
No. 9	43,400	165.6
No. 10	43,400	165.6
No. 11	40,700	155.4
No. 12	40,700	155.4
Total	469,800	1,793.8

All topside ballast tanks, peak tanks, double bottoms, coal bunkers and the fireroom bilges are painted with bitumastic paint; the coal holds and engine-room bilges are red leaded; the oil holds are coated with oil.

There is no artificial ventilation in the ship except for the oil holds. Ventilators are led down from the superstructure to all living spaces. They are entirely inadequate for the lower decks.

COAL-HANDLING GEAR.

The coal-handling gear was furnished by the Mead, Morrison Mfg. Co. Their contract calls for a delivery of 100 tons per bucket per hour when the gear is operated by a winchman of one week's experience.

The support for the booms and rigging is a tower which consists of two A-frames, tied together with X-braces. There are seven of these towers in the waist of the ship and one on the superstructure. There is a single A-frame between the two after (7 and 8) towers, which acts as an additional support for the fore-and-aft trolley way which runs between

towers 6 and 8. This trolley way is a semi-box girder and takes the place of the 'thwartship cable span when transferring coal from hold No. 13 to No. 1 bunker.

At each tower, except 1 and 8, there are four booms, two on each side of the tower. Nos. 1 and 8 towers have only two booms each. The heel of each boom steps into a socket on the side of the tower and is supported by a standing-wire topping lift; there are two guys for holding the boom in the proper position in a fore-and-aft direction. The 'thwartship cable span, which acts as a track for the trolley, runs from a boom head on one side of the ship to a boom head on the other side, the forward pair of booms on each tower plumbing the hatch just forward of it, and the after pair of booms the after hatch. The cable span gives a travel of twenty feet beyond each side of the ship and has sufficient height to clear the deck of a battleship twenty feet above the collier's deck. Each boom has a manila topping lift for topping it up into a vertical position for securing; it is held in this position by a pin and also by a wire preventer.

There are two winches, one clam-shell bucket of one ton capacity (three-quarter for the bunker), and a trolley, for each pair of booms.

One winch has two drums, one for holding, the other for opening and closing; the other winch has one drum for traversing.

The trolley consists of a carriage with two sheaves in the top half which travel on the cable span and with four sheaves in the lower half, these being for the opening and closing and holding lines. The line for traversing also makes fast to the trolley, but runs through no sheave in it.

The grab bucket is provided with an upper head, to which the links are pivoted, and with a bottom head, to which the segments of the shell are pivoted; there is a triple block in the lower head and a double block in the upper head. The shell of the bucket is ⅜-inch steel plate, reinforced at the mouth with 1-inch × 8-inch steel jaws, beveled at the cutting edge.

The shell segments are hinged to the bottom head and are connected by links to the upper head; the construction of the bucket is such that when suspended from the upper head the segments will swing open and stay open till the upper and bottom heads are pulled together by the opening and closing line, which reeves through the blocks in the upper and bottom heads. There are supplied ten 1-ton, and three ¾-ton grab buckets.

The bucket is suspended in a bight by both the opening and closing and holding lines, thus making these lines independent of the position of the trolley. The traversing line is continuous, so that it unreeves on one side of its drum as fast as it reeves off on the other side. One end of the opening and closing line makes fast to a boom head (the one on the opposite side of the ship from its winch), it then reeves over a sheave in the trolley, then through triple and double blocks in the bottom and upper heads of the bucket, then back through a sheave in the trolley, then through a sheave in the boom head (the one on the same side of the ship as the winch), then up to a sheave in the top of the tower, then down to the drum of the winch, where it makes fast. The lead for the holding line is practically the same as that for the opening and closing line; the difference is that it reeves through a single block attached to the upper head of the bucket. The main function of this line is to support the bucket when the opening and closing line is slacked off; the normal position of the bucket being wide open, it immediately swings into this position as soon as the opening and closing line is slacked; when this line is taken in, the double and triple blocks on the bucket are pulled together, and this pulls the two halves of the bucket together and keeps them that way as long as the line is kept taut. The opening and closing line really acts also as a hoisting line, and as soon as the bucket is closed both opening and closing line and holding line are taken in together, and both act to hoist the bucket. The traversing line makes fast to a pin on the trolley, then reeves through a sheave at the boom head, then

through a sheave (fair lead) on the side of the tower, then through a sheave in the tower, then around the winch drum, then through a sheave in the tower, then through a sheave (fair lead) on the side of the tower, then through a sheave in boom head, then back to a pin on the trolley, making the circuit continuous from one side of the ship to the other.

The hoisting engine is twin cylinder with 10-inch diameter and 12-inch stroke; it runs in only one direction and has a throttle operated by a foot lever. It has two drums, both of which are engaged by conical frictions covered with leather; these are operated by hand levers. There is a friction-brake band for locking the holding drum, and this is operated by a foot lever; this brake is used when it is desired to keep the bucket suspended for any considerable period of time. The hoisting engine also has an extension gypsy head for hoisting hatch covers, booms, etc. The winch is operated by steam at 135 pounds pressure per square inch.

The trolley engine is twin cylinder with 8½-inch diameter and 10-inch stroke; it has reversing links for changing the direction of rotation, and this is operated by a hand lever; the throttle is operated by a foot lever. The drum is split in two halves by a plane at right angles to its axis; one-half of the drum is locked by a key to the rotating shaft and the other half is locked by a conical friction which is operated by a thrust screw and nut on the end of the shaft. This friction is ordinarily in all the time when running and is only thrown out when it is desired to take up the slack of the trolley wire, which must always be kept taut; to take in the slack of this wire the friction half of the drum is slacked off and held from rotating by a brake band operated by a hand lever; the other half of the drum is then rotated until all the slack is taken up; the engine is then stopped and the two halves of the drum are locked together by the thrust screw and jamb nut. The after trolley engine has an extension on the drum shaft and a second trolley drum on this extension; the second drum is thrown in or out by a clutch, and is used for operating the fore-and-aft

trolley and taking coal out of No. 13 cargo hold for bunker purposes. The gear for holding, opening and closing, and traversing is all rove off on the after tower for fore-and-aft coaling in practically the same way that it is for the transverse method, except that the leads are in a fore-and-aft direction instead of 'thwartships.

In addition to the use of buckets coal can also be handled by either the transverse or fore-and-aft method by using four-pronged hooks for bags or by using skips, the latter being intended particularly for the ship's bunkers.

Each bucket requires two men to operate it, one man to open and close and hoist and lower, and another man to traverse. The bucket operator has two hand levers and one foot lever to operate; his right-hand lever operates the opening and closing and the left-hand lever the holding line; the foot lever operates the throttle of the engine. The trolley operator has a hand lever for moving the reversing links and a foot lever for the throttle. Starting with the bucket open and on the coal in the hatch, the operation is as follows:

The bucket operator puts his right foot on his throttle and starts his engine, then throws in with his right hand the opening and closing drum which pulls the bucket together, then throws in with his left hand the holding drum, and the two drums hoist the bucket to the desired height; he then takes his foot off the throttle and stops his engine. The trolley operator will already have his links thrown in the proper position, and when the bucket comes up clear of the hatch he starts his engine by putting his left foot on the throttle lever, and when he has moved the bucket over the deck of the battleship, he takes his foot off the throttle and stops his engine; he then throws his links into the reverse position for the return trip. As soon as the bucket is over the deck of the battleship the bucket operator throws out the opening and closing drum and the bucket immediately swings open. The trolley operator then starts his engine and returns the bucket to the hatch, when he stops his engine and throws over his links

for the next trip. As soon as the bucket is over the hatch the bucket operator releases his hoisting and holding drums and lets the bucket drop on the coal, completing the cycle. The bucket will probably close as it drops, in which case the bucket operator will throw in his holding drum just before the bucket reaches the coal; the bucket will then open, and he can throw out his holding drum, dropping the bucket on the coal.

The operating platform is situated about twenty-five feet above the deck and inside the tower. The levers are placed here and are connected up to the engines by means of shafts and bell-crank levers. From this position, the operator can always see his bucket, both when taking coal out of a hatch on the ship and also when taking it from a barge or another ship alongside. The levers were changed to this position after a trial with them when placed on the deck alongside the winches. A great deal of trouble was experienced with the operation under these conditions and it was also necessary to have a third man stationed at the rail to give signals when taking coal from a barge alongside.

OIL-HANDLING SYSTEM.

For filling and emptying the cargo holds there are four 6-inch gate valves on the forecastle and 6-inch wrought-iron pipes which lead from these valves down through the forecastle, where two on each side join into an 8-inch pipe, and these two 8-inch pipes in turn connect to a 10-inch riser, which leads down to the pumps in the pump room. There are also two 6-inch connections with blank flanges on the side of the ship which also join the 10-inch riser.

In the pump room are two 14-inch × 12-inch × 12-inch horizontal duplex pumps, manufactured by the Canton Hughes Co. They are rated at 1,000 gallons per minute each, with a steam pressure of 130 pounds. From these pumps two 10-inch wrought-iron suction and filling lines lead aft along each side of the center-line bulkhead with a 10-inch stop valve in each

oil hold operated by a hand wheel on the upper deck. These lines are carried on top of the floor in holds 1, 2, 3 and 4 and in the double bottoms under holds 5, 6, 7 and 8. An 8-inch connection for flooding tanks is provided on the suction side of the pump and carried to the sea valve in the forward trimming tank. A 10-inch Macomb strainer is fitted on each pump suction. Each oil hold is also provided with a 2-inch hand-pump suction which leads to a manifold on the bulkhead and thence to a hand pump on a grating in the pump room.

Heating coils of 1-inch pipe are fitted about the 10-inch suction in each hold; they are supplied with steam from the pump room and drained into the auxiliary exhaust on the upper deck.

Cross connections in the pump room allow pumping with either one or two pumps, from one hold to another, overboard, or from overboard.

A No. 3 Sirocco fan placed on the berth deck above the pump room is connected to the 10-inch oil suctions for removing gas from the various holds.

FIRE-MAIN AND FLUSHING SYSTEMS.

Either of these systems can be operated by the salt-water sanitary pump, ballast pump, or the fire and bilge pump. The salt-water sanitary pump is a 6-inch × 8½-inch × 6-inch horizontal, duplex, Blake pump, rated at 350 gallons per minute. The ballast pump is a 7½-inch × 9-inch × 10-inch vertical, duplex, Blake pump, rated at 660 gallons per minute. The fire and bilge pump is a 12-inch × 8½-inch × 12-inch vertical, duplex, Blake pump, rated at 590 gallons per minute. All three pumps have 6-inch suctions from the same sea chest, which is in the starboard forward corner of the engine room near the pumps.

The flushing system has a 3-inch galvanized wrought-iron riser leading directly from the discharge side of the sanitary pump up through the engine-room hatch on the starboard side; on the upper deck there is a cross-connection to the fire

main. The riser reduces gradually until at the water closets there is a 1-inch line to the bowls and a ¾-inch line to the salt-water faucets and showers. The two water closets forward are flushed from the fire main.

The fire and bilge pump and ballast pump have a cross-connection to a 5-inch discharge to which the fire main connects. There is a 7-inch galvanized wrought-iron riser which leads from this cross-connection up the forward engine-room bulkhead on the starboard side to the level of the berth deck; from here a 4-inch branch is led up under the poop deck and aft reducing in size to 2½-inch diameter, and supplying 2½-inch fire plugs on the upper and poop decks. The 7-inch riser continues forward under the berth deck on the starboard side until it reaches the forward fireroom bulkhead, where it divides into two 6-inch branches, one running forward on the starboard side and the other on the port, both above the upper deck. These branches both reduce in size to 3½ inches and supply 2½-inch fire plugs on the upper deck and forecastle. There are 3½-inch stop valves which admit water to topside ballast tanks and also to the cofferdam. In the fireroom, 2½-inch connections are taken off for both ash chutes.

Both of the forward branches and also the after one are controlled independently by cut-out valves.

STEAM FIRE-EXTINGUISHER SYSTEM.

From the steam line to the anchor engine there is taken off a ¾-inch branch which leads forward and branches, one part leading to the lamp room and the other to the paint and oil room.

From the same steam line is taken off a steam manifold for the four forward oil holds, each hold having a separate pipe and valve.

From the auxiliary line in the waist of the ship is taken off a steam manifold for holds 5, 6, 7 and 8; each hold has separate pipe and valve.

REFRIGERATING SYSTEM.

The refrigerating system consists of a 3-ton ammonia ice machine with a 7-inch × 10-inch ammonia compressor and 9¼-inch × 10-inch engine, a brine tank 4 feet 9½ inches × 22 inches × 4 feet 1 inch, a 4½-inch × 2¾-inch × 4-inch duplex double-acting Deane pump for circulating cooling water, a similar pump for circulating brine, and a refrigerator room divided into four compartments and containing 2,884 cubic feet stowage space.

The ammonia machine and brine tank were furnished by the Vilter Mfg. Co., of Milwaukee.

Each of the refrigerating rooms has its own cooling coil which is independently controlled; there is also a brine pipe and return leading to the scuttle-butt on the upper deck.

BILGE AND BALLAST SYSTEM.

The function of the bilge system is to draw water from the bilge wells in the engine room, fireroom and cargo holds, and discharge it overboard by means of the fire and bilge or ballast pumps, acting singly or in unison.

The function of the ballast system is to either fill or empty the peak tanks or double bottoms which are used for ballasting. These compartments may also be filled to a certain height by gravity from two sea valves, a 6-inch valve in the engine room and a 7-inch valve in the fireroom. Either the fire and bilge or ballast pump or both pumps can also be used on this system, as the bilge and ballast systems are cross-connected in the engine room.

The bilge system has a 4-inch main leading aft from the pump in the engine room and a 6-inch main leading forward; in the fireroom this main branches and leads to two manifolds, one on each side of the forward fireroom bulkhead; from these manifolds 3-inch suction lines lead to both sides of the coal cargo holds. In the after end of the fireroom another branch is taken off the 6-inch main, and this leads to a manifold on the

after bulkhead of the fireroom; from this manifold two 3-inch pipes lead off to starboard and port to bilge wells in the after end of the fireroom. The 4-inch main in the engine room leads to a manifold on the after engine-room bulkhead. From this manifold 3-inch suctions lead off to starboard and port to bilge wells in the after end of the engine room. From this 4-inch main is also taken a 4-inch branch which leads to a manifold near the pump; from this manifold one 3-inch pipe leads down to a bilge well near the manifold; another 3-inch pipe leads across to the port side of the engine room to a bilge well; there are two 2-inch lines, with valves, tapped into this, which lead to the two motor pits.

The ballast system has a 6-inch sea suction connected to the manifold in the engine room near the pump; this manifold has a longitudinal wall separating it into two parts, one for filling and the other for discharging; it also has a valve connecting the two so that water can be pumped into the tanks as well as flowing into them by gravity. From this manifold, two 4-inch suction or filling lines lead to the two after peak tanks; also a 4-inch line leads to the fresh water manifold on the port side of the engine room; also a 7-inch line leads forward into the fireroom to two manifolds, one on each side of the forward fireroom bulkhead; from these manifolds 3-inch suction lines lead to double bottoms 6 to 11, inclusive. This 7-inch main also connects to a manifold in the middle of the forward fireroom bulkhead; from this center manifold there leads a connection to a 7-inch sea suction on the port side of the fireroom; also 4-inch suction or filling lines lead from it to the forward-peak tank and double bottoms 5 to 11, inclusive.

The valves in all these manifolds are of the plug type. The bilge wells are galvanized-iron castings. The piping is galvanized wrought iron, excepting sharp bends, which are of No. 12 B.W.G. copper, and the bilge-suction tail pipes, which are of lead, ¼ inch thick. The sea chests are cast iron. Pipes passing through bulkheads are fitted with galvanized cast-iron stuffing boxes with brass glands.

The topside ballast tanks are filled from the fire main and empty by gravity through 4-inch drain valves operated on the upper deck.

ANCHOR ENGINE AND ANCHORS.

The anchor engine was built at the Mare Island Navy Yard and is of the spur-geared type fitted with two wildcats to handle 2-11/16-inch chain and having two gypsy heads. The windlass is driven by two direct-connected horizontal 12-inch × 16-inch engines bolted directly to the bitts and provided with a reversing valve of the piston type.

There are two patent bower anchors weighing 10,150 and 10,180 pounds, respectively, one patent bower anchor weighing 8,500 pounds, one patent stream anchor weighing 3,220 pounds, one patent kedge anchor weighing 1,505 pounds and two small sea drags.

STEERING GEAR.

The steering engine was manufactured by the Hyde Windlass Co. It is located on the upper deck aft, and can be operated by a wheel from the flying bridge, lower bridge or after bridge. It can also be operated by hand wheels at the engine. The engine is twin cylinder 10 inches × 8 inches. The area of the rudder is 208.6 square feet.

BOATS AND CAPSTAN WINCH.

The ship has one 33-foot motor sailing launch fitted with a two-cylinder, two-cycle, Norfolk Navy Yard gas engine; one 21-foot motor dory fitted with a Loew, single-cylinder, four-cycle gas engine; two 28-foot whaleboats; one 20-foot work boat; two life rafts. The whaleboats and motor sailing launch hoist on davits of the tipping type and the dory and work boat on davits of the swinging type; all boats stow on a level with the superstructure deck and are hoisted by a capstan winch

on the after end of the poop. This winch was supplied by the Hyde Windlass Co., is twin cylinder, 8 inches × 8 inches, and is reversible.

EVAPORATING AND DISTILLING PLANT AND FRESH-WATER SYSTEM.

This plant is situated on a platform on the port side of the after end of the engine room. It consists of two Reilly multi-coil evaporators having a capacity of 26 tons per day, and two Reilly multi-coil distillers rated at 3,000 gallons per day, and the following pumps:

1 Vertical duplex Blake evaporator feed pump, 4½-inch × 2¾-inch × 4-inch.

1 Vertical duplex Blake distiller circulating pump, 5¼-inch × 5-inch × 5-inch.

1 Horizontal duplex Blake fresh-water pump, 2-inch × 1¼-inch × 2¾-inch.

1 Vertical duplex Blake fresh-water sanitary pump, 4½-inch × 3¾-inch × 4-inch.

There is a 2½-inch filling line with a 2½-inch hose connection on either side of the ship aft; these connect together and run down into the engine room to the fresh-water manifold on the port side of the forward end of the engine room; from this manifold, 2½-inch galvanized wrought-iron pipes run to the four reserve feed tanks; the bottom-blow line from the boilers also connects to this manifold; there is also a connection from the main feed tank to this manifold; the auxiliary feed pump takes its suction from this manifold.

The filling line also has branches leading to the ship's fresh-water tanks in the ice-machine room.

ELECTRIC PLANT.

There are three 3,600-r.p.m., 125-volt, two-pole, 35-kw. generators supplied by the General Electric Co. They are situated on a platform in the starboard after end of the engine

room. They supply current for lighting and power and also for exciting the field of the main generator, but can not be used for both purposes at the same time; the main and field switches on the lighting board are double throw.

The lighting switchboard is on the same platform as the generators and consists of three generator panels and one lighting panel.

There is a 24-inch searchlight on the foremast just above the crow's nest.

The radio plant consists of a 5-kw., 500-cycle, Fessenden set, manufactured by the National Electric Signaling Co.

There is an experimental radio set on board temporarily installed for experimental purposes. It was supplied by the Federal Telegraph Co. and is a 12-kw. Poulsen set.

There is an ardois signaling set on the foremast with a telephotus on the flying bridge.

There is a 6-H.P. 125-volt, series motor with starting panel, controller, and resistances for operating the jacking gear. The motor runs about 600 r.p.m. and is geared down so that the propeller shafts will turn once every twelve minutes. The jacking gear consists of a worm wheel on each propeller shaft, gearing into a worm on a vertical shaft; these two vertical shafts are cross-connected by bevel gears and a countershaft; the countershaft has a pinion which is connected by a chain drive to the jacking motor.

AUXILIARY CONDENSER.

The auxiliary condenser was supplied by the Blake Pump Co.; it has 1,200 square feet of cooling surface and an auxiliary air and circulating pump 12-inch × 14-inch × 14-inch × 12-inch. The condenser is 9 feet 5½ inches long and 2 feet 7 inches in diameter. The auxiliary air and circulating pump returns the condensed water to either main or donkey feed tanks.

MAIN-ENGINE AUXILIARIES.

There are two centrifugal main circulating pumps which were manufactured by the Mare Island Navy Yard. They have a 42-inch runner, width at tip 3½ inches, diameter of inlet 14 inches, outlet 14 inches. They are driven by vertical single-cylinder engines 10 inches × 8 inches. The capacity at 280 r.p.m. is 8,000 gallons per minute for each pump.

There are two main dry-air pumps manufactured by the Alberger Pump & Condenser Co. They are vertical engines with single steam and air cylinders, steam cylinders 10 inches × 14 inches and air cylinders 24 inches × 14 inches. The suction valve on the air cylinder is a flat slide valve, and the discharge valves are spring-loaded valves.

There are two main wet-air pumps supplied by the Alberger Pump & Condenser Co. These are volute pumps, driven by a one-wheel impulse turbine, running about 3,000 r.p.m. They will pump against a 25-foot head of water, so it was possible to let them discharge directly into the measuring tanks, which are above the feed tank, and drain into the latter by gravity.

The main condenser was manufactured at the Mare Island Navy Yard in accordance with drawings prepared by the Alberger Pump & Condenser Co. It is 7 feet 2 inches diameter, and 10 feet 6 inches long. It contains 5,652 tubes, ⅝-inch outside diameter, which give 10,000 square feet of cooling surface. The condenser lies in an athwartship position, and the exhaust trunk from the turbine comes in on the forward side of the condenser; this trunk is 8 feet 8 inches × 3 feet 9 inches and of rectangular cross-section at the condenser end; it is oval in shape at the bottom, being composed of a rectangle and two semi-circles, the rectangular part being 4 feet 2 inches × 36 inches and the semi-circles being 36 inches in diameter. The circulating water enters at the top and leaves at the bottom of the starboard end of the condenser. The tubes are expanded in the port end and packed in the starboard end of the condenser.

The feed heater is on the port side of the forward engine-room bulkhead, over the feed pumps; it is a Reilly multi-coil heater, capable of handling feed water for 7,200 I.H.P. It is arranged with cut-out valves so that it may be by-passed when so desired. The heating agent is auxiliary exhaust steam, and this line is so arranged as to give the following different combinations:

(1) All auxiliaries can be run into the heater and the drain run into the auxiliary condenser.
(2) The exciters can be run into the main condenser and all other auxiliaries into the heater and the drain from that into the auxiliary condenser.
(3) The exciters can be run into the main condenser and all other auxiliaries into the heater and the drain from that into the main condenser.
(4) All auxiliaries can be run into the auxiliary condenser.
(5) All auxiliaries can be run into the main condenser.

There are two forced-draft Sturtevant fans, 7 feet in diameter, driven by twin-cylinder engines 6 inches × 5 inches. They are situated in the blower room directly over the donkey boiler, and have suctions from the fireroom and also from the ventilating ducts of the main generator and motors. The capacity is 30,000 cubic feet of air per minute delivered against a head of 3 inches of water pressure at speed of 350 r.p.m. These blowers deliver to the ash pits and furnaces of the main boilers, the air first passing around vertical tubes in the smoke boxes.

There is a 6-inch × 4-inch × 6-inch horizontal, duplex Deane pump secured to the port side of the main turbine foundation. This is used for supplying oil under pressure to the turbine bearings and also to the cylinder of the governor relay when starting up the turbine.

There is a 3-inch × 2-inch × 3-inch horizontal duplex Worthington pump on the starboard side of the main turbine and about 22 inches below it, which takes the water from the drains of the turbine casing.

STEAM AND EXHAUST LINES.

All high-pressure steam pipe of 2-inch, 2½-inch, 3-inch and 3½-inch diameter is seamless-drawn copper, with brazed flanges. All high-pressure steam pipe from 3½-inch to 6½-inch diameter is seamless-drawn steel, rolled into wrought-steel flanges. All high-pressure steam pipe 7½-inch diameter and over is seamless-drawn steel with cast-steel flanges riveted on. Steam lines to deck machinery are of lap-welded steel pipe; all over 6½-inch diameter have cast-steel flanges riveted on; all 6½-inch diameter and under are rolled into wrought-steel flanges. Branch steam pipes are extra heavy wrought-iron, iron-pipe size, with extra heavy malleable-iron, screwed fittings.

The auxiliary exhaust lines over 10 inches in diameter are of lap-welded steel, iron-pipe size, with cast-steel flanges riveted on. The auxiliary exhaust lines 10 inches in diameter and under are of lap-welded steel, iron-pipe size, with cast-iron flanges screwed on. Branch exhaust pipes 1½ inches in diameter and under are wrought-iron, with malleable-iron screwed fittings. Branch exhaust pipes 2 inches in diameter and over are of copper with brazed flanges. The exhaust from the deck machinery is lap-welded steel pipe, iron-pipe size, with cast-iron screwed flanges.

An expansion joint is fitted on each of the two 10-inch branches of the main steam line in the fireroom. Two expansion joints are fitted on the steam line to the deck machinery and also two on the exhaust line from the same.

The risers from the boilers are 7 inches in diameter, and these connect to two 10-inch lines, which run to the forward engine-room bulkhead and there unite; an 8-inch line runs from there to the turbine.

The auxiliary steam line in the engine room runs all the way around the engine room and cross-connects to the main steam line on both sides at the forward engine-room bulkhead; it is 6 inches in diameter.

FEED LINES.

The main and auxiliary feed lines are seamless-drawn copper, with brazed flanges; the main lines are 5 inches in diameter, reducing to 3 inches diameter at the boilers. The two lines are entirely independent. The auxiliary line can be used for feeding the donkey as well as the main boilers. The surface and bottom-blow pipes are 2½ inches in diameter, connecting to a 3½-inch overboard discharge, and are of the same material as the feed line. This 3½-inch line connects to the donkey-boiler feed pump and to the auxiliary feed pump through the fresh-water manifold, so that the water in a main boiler can be circulated by taking a suction through the bottom blow and discharging back through the auxiliary feed line.

The main and auxiliary feed pumps are 12-inch × 8½-inch × 12-inch vertical, duplex, Blake pumps with metal valves. The main feed pump takes its suction directly from the main feed tank and the auxiliary feed pump takes its suction from the fresh-water manifold, which has a suction to the main feed tank.

The donkey-boiler feed pump is a vertical, simplex, Blake pump, 6-inch × 3½-inch × 8-inch. It has suctions from the donkey-boiler feed tank in the fireroom and from the bottom blow line, so that it can be used either for feeding the donkey boiler or for circulating water in the main boilers.

BOILERS.

There are three double-ended, return-tubular, marine type, Scotch boilers, and one upright donkey boiler. The main boilers have the following dimensions:

Length over all, feet and inches	23–00¾
Diameter, feet and inches	16–03
Number of furnaces per boiler	8
Diameter of furnaces (inside), inches	40
Length of grates, feet and inches	5–07½
Grate surface per boiler (in square feet)	150
Heating surface per boiler (in square feet)	6,460
Ratio of G.S. to H.S	1 : 43.06

These boilers are designed for a working pressure of 190 pounds per square inch, but the safety valves are to be set for 200 pounds per square inch for the trials. Howden's forced-draft system is used. There are three louvres to each furnace; escaping gases pass through the vertical tubes in the smoke box and the incoming air from the blowers passes around these tubes, having been previously heated by the generators and motors.

Donkey boiler has the following dimensions:

Height above foundation, feet and inches	12–05
Diameter, feet and inches	7–02
Grate surface in square feet	33.183
Heating surface in square feet	1160.37
Ratio of G.S. to H.S.	1 : 34.24

This boiler has a separate feed tank, feed pump and an injector.

The boilers are covered down to the saddles with 1½-inch block magnesia, plaster and galvanized iron.

There are two smoke stacks, one on each side of the ship; boilers Nos. 1 and 2 deliver into the starboard stack; boilers Nos. 2 and 3 and the donkey boiler deliver into the port stack; there is a damper for shutting off the donkey boiler uptake when it is not in use. The stacks are 9 feet × 5 feet 6 inches in diameter, with 3-inch air space, and are 98 feet 6 inches above the center line of the middle furnaces. The whistle is on the starboard stack and the siren on the port. Both stacks are fitted with ladders.

There are two ash hoists in the fireroom—one in the starboard after end of the fireroom, the other in the port forward end. They lead up to a level with the berth deck where there are access doors to platforms which have overhead trolleys running out to ash chutes at the side of the ship. The hoisting engines are steam rams, 5 inches × 10 feet 3 inches.

PROPELLERS.

There are two solid, manganese-bronze propellers. They have a taper fit on the tail shaft and are keyed and held in place by a bronze nut. They have the following dimensions:

Diameter, feet and inches	15–11 $\frac{7}{16}$
Pitch, feet and inches	14–05 $\frac{1}{16}$
Expanded area, square feet	70.5
Projected area, square feet	60.53
Disc area, square feet	198.97
Weight, one propeller, pounds	13,900

SHAFTING, BEARINGS, ETC.

All shafting is of forged steel and solid except the forward section on each shaft, which has a 3½-inch hole for torsion meters.

There is a Gary-Cummings torsion meter fitted on each intermediate shaft. For description of this instrument, see Volume XXIV, of the JOURNAL OF AMERICAN SOCIETY OF NAVAL ENGINEERS.

The shafts are inclined down at an angle of 0 degrees 56 minutes–56.5 seconds, or .198198 inch per foot, and they diverge from centerline of the ship at an angle of 1 degree 9 minutes 40.5 seconds, or .24324 inch per foot.

Shaft Data.

Intermediate shaft, diameter, inches	14¾
length, feet and inches	10–11 $\frac{11}{16}$
Thrust shaft, diameter, inches	14¾
length, feet and inches	16–03
Stern-tube shaft, diameter, inches	15⅝
length, feet and inches	28–03½
Propeller shaft, diameter, inches	15¾
length, feet and inches	33–02¼

All flange couplings are secured by taper-fitted forged-steel bolts.

The propeller shaft is covered through the stern-tube bear-

ings with composition sleeves 7/8 inch thick; the sleeves are shrunk on with joints between sections soldered.

Bearing Data.

Thrust bearings, number	2
length, inches	12¾
Collars on thrust shaft, number	9
thickness, inches	02⅛
space between, inches	04¾
outside diameter, inches	24
inside diameter, inches	14¾
bearing surface, square inches	2,533.68
Thrust shoes, number	9
effective thrust surface, square inches	1,730.07
Stern-tube bearings, number	2
length forward bearings, feet and inches	2–05
length after bearings, feet and inches	4–05½
bearing surface	Lignum vitae.
Strut bearing, number	1
length, feet and inches	4–05½
bearing surface	Lignum vitae.

The thrust block is of cast iron fitted with an oil trough. The block rests on a heavy cast-iron sole plate with a long base well secured to the structure of the ship.

MAIN ENGINES.

The installation of motors and generators on board ship for propelling purposes is an attempt to make use of the good efficiencies of high-speed turbines without sacrificing the efficiency of low-speed propellers. The weight of such installation is less (as will be seen from figures given later on) and the space is less also than any of the present installations of either turbines or reciprocating engines.

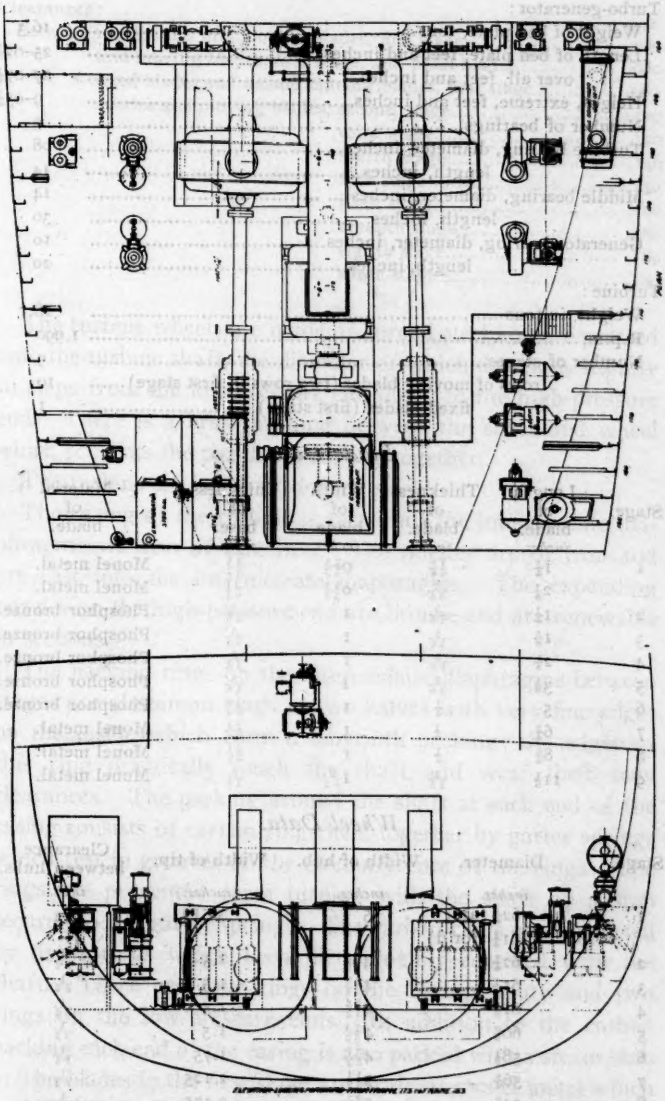
As compared with other methods of speed reduction, such as gears, etc., it has the advantages (1st) that the ratio of reduction can be varied (that is, by winding the motors for different numbers of poles, the ratio of motor and generator can be varied), (2d) that at low powers only part of the

plant need be used (that is, if two generators are installed, only one need be used at a time), and (3d) that there is no need for a backing turbine, which is usually inefficient and gives very little torque. It will be seen that these advantages are much more marked in a ship using wide ranges of speed and power, such as a battleship, than in a ship running always at nearly the same speed, such as a collier; however, for the latter class if the method of propulsion proves a success, it is very probable that electrically-driven winches will take the place of the present steam-driven winches. The present claims of the contractors for the machinery of the *Jupiter* are that it is lighter, takes up less space, and is more efficient than any other form of ship propulsion. Of the first two claims there is little doubt, but the matter of efficiency has yet to be proved on trial, as has also the more important one of practicability; neither of these points can be proved except by a long period of trial in service.

The installation on the *Jupiter* consists of one Curtis turbo-generator, two induction motors, two water-cooled rheostats, and one main switchboard; the excitation for the main generator is taken from one of the ship's 35-kw. generators.

The turbo-generator furnishes power to the motors, the function of the generator and motors being solely that of a reduction gear. All changes of speed are made by changing the speed of the turbine, thus varying the frequency of the generator and consequently the speed of the motors. The generator is two-pole and the motors are thirty-six-pole. The speed-reduction ratio is therefore practically one to eighteen; the slip of the motors will vary a little for different loads and alter the ratio a slight amount. The motors are wound for only one number of poles and therefore the speed ratio is not changeable as it would be for a battleship installation; the reason for this is that such change is not necessary, as the cruising speed of the ship is practically her maximum speed.

The following general data will show the character of the machinery:



ARRANGEMENT OF MACHINERY, COLLIER "JUPITER." ELECTRIC DRIVE.

Turbo-generator:

Weight of bed plate, tons	16.3
Length of bed plate, feet and inches	25–02½
over all, feet and inches	27–07½
Height, extreme, feet and inches	9–05½
Number of bearings	3
Turbine bearing, diameter, inches	08
length, inches	14
Middle bearing, diameter, inches	14
length, inches	30
Generator bearing, diameter, inches	10
length, inches	20

Turbine:

Weight, in tons	28.7
R.p.m.	1,990
Number of stages	9
rows of moving blades (two rows in first stage)	10
fixed blades (first stage)	1

Blade Data.

Stage.	Length of blade. *inches.*	Thickness of blade. *inch.*	Width of blade. *inches.*	Thickness of base. *inch.*	Material of blade.
1	1¼	19/64	0 25/32	15/32	Monel metal.
...	2¼	7/64	0 25/32	21/64	Monel metal.
2	1½	5/16	1	5/16	Phosphor bronze.
3	1⅝	5/16	1	5/16	Phosphor bronze.
4	2⅛	5/16	1	5/16	Phosphor bronze.
5	3⅛	5/16	1	5/16	Phosphor bronze.
6	5	¼	1	19/64	Phosphor bronze.
7	6¾	¼	1	21/64	Monel metal.
8	8¾	¼	1	21/64	Monel metal.
9	11⅛	5/16	1 9/32	5/16	Monel metal.

Wheel Data.

Stage.	Diameter. *inches.*	Width of hub. *inches.*	Width of tip. *inches.*	Clearance between hubs. *inch.*
1	62¼ (aft) 61¼ (for'd)	5	3.519	1/32
2	62¼	4 13/32	1.5	1/32
3	61⅞	4 23/32	1.5	1/32
4	61⅜	4 23/32	1.5	1/32
5	60⅝	4 23/32	1.5	1/32
6	58½	4 31/32	1.75	1/32
7	56¾	5 11/32	2.125	1/32
8	54¾	5 23/32	2.375	1/32
9	52½	5⅝	3.25	1/32

Clearances:	inch.
Between nozzles and first moving blades, first stage	.080
first moving blades, first stage, and fixed blades	.080
fixed blades and second moving blades, first stage	.080
nozzles and moving blades, second stage	.120
third stage	.120
fourth stage	.140
fifth stage	.140
sixth stage	.160
seventh stage	.160
eighth stage	.180
ninth stage	.180

The turbine wheels are made of forged steel and are pressed onto the turbine shaft, the diameter of which decreases slightly in steps from the low-pressure end down to the high-pressure end. There is a brass bushing between the shaft and wheel which prevents the two from rusting together.

The turbine shaft is solid forged steel.

The casing of the turbine is cast iron; the intermediate diaphragms are also of cast iron. The nozzles are of iron and are cast into the intermediate diaphragms. The expanding nozzles on the high-pressure end are bronze and are renewable in sections.

The packing rings on the intermediate diaphragms between stages are aluminum rings in two halves with very fine edges on the inside which form a labyrinth packing; the edges of this ring practically touch the shaft and wear their own clearances. The packing around the shaft at each end of the casing consists of carbon rings held together by garter springs which rest in grooves on the circumference of the rings. The rings are prevented from turning with the shaft by a stop secured to the garter springs. The carbon rings are supported by flat springs which keep them flexibly centered with the shaft. There are four rings on the high-pressure and two rings on the low-pressure ends. In addition to the carbon packing each end of the casing is also packed with a steam seal.

The blades in the first stage are made of monel metal which resists the erosive effect of the very hot, fast-moving steam;

the blades in the seventh, eighth and ninth stages are also made of monel metal to resist the corrosive effect of any water that might collect in those stages; the blades in the second, third, fourth, fifth and sixth stages are made of bronze.

The bearings are of the spherical, self-aligning type and both upper and lower halves are water-cooled, the water passing through coils embedded in the babbitt. Water for this purpose is furnished by the main circulating pumps or the salt-water sanitary pump. Oil is supplied, under pressure, to the bearings and also to the cylinder of the governor relay by a cycloidal-gear pump situated on the lower end of the governor shaft. The oil reservoir is in the bed plate of the turbine and is fitted with air vents and an indicator. Oil passes through a large strainer before going to the pump; after leaving the pump it goes through an oil cooler which gets its cooling water from the same water service that the bearings do; from the cooler the oil goes through a fine-mesh strainer, then through a reducing valve (set at 25 pounds pressure per square inch) to the bearings, and returns by gravity to the reservoir; the oil for the cylinder of the governor relay does not go through the reducing valve but goes direct to the cylinder and is maintained at 75 pounds pressure by relief valves which discharge into the reservoir.

The governor is mounted on a vertical shaft driven by a gear from the main shaft. It consists of weights resting on knife edges and acting by centrifugal force against a coiled spring; the motion of the weights operates a small pilot valve which admits oil, under pressure, to the cylinder of the relay which operates a rack, gearing with a pinion on the cam shaft; the position of this shaft determines the number of control valves that are open. At the end of the governor arm which operates the pilot valve is connected up a diamond-shaped frame or parallel-motion transmitter which is connected by a system of rods and bell-crank levers to the operating stand in front of the switchboard. The motion of a small wheel on this stand alters the fulcrum about which the governor acts on the

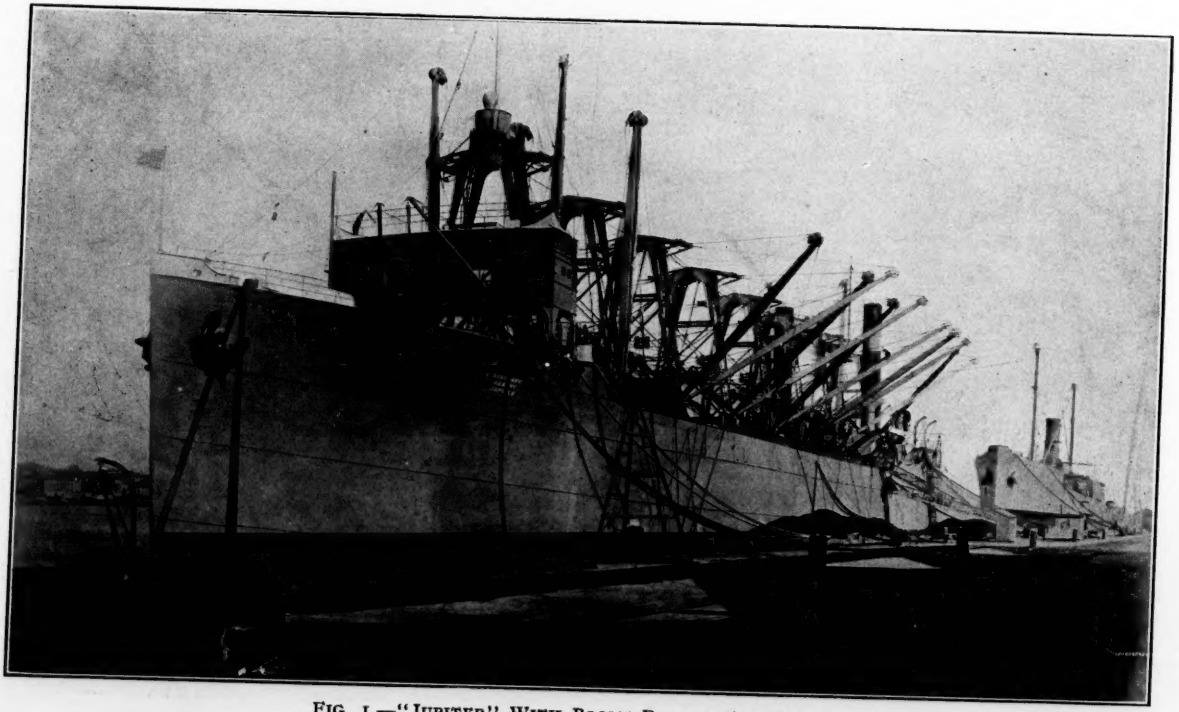


FIG. 1.—"JUPITER" WITH BOOMS RIGGED FOR COALING.

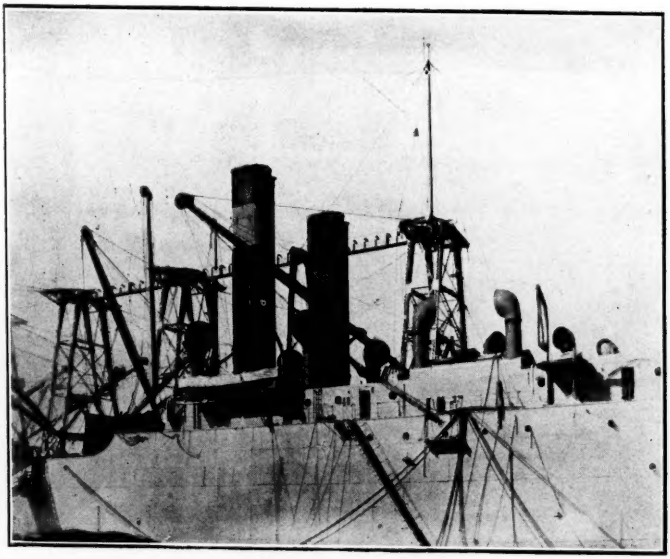


FIG. 2.—FORE-AND-AFT TROLLEY.

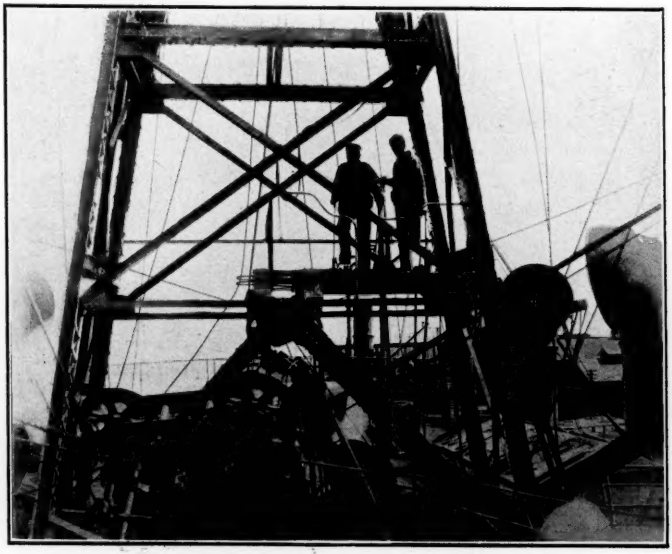


FIG. 3.—OPERATING PLATFORM.

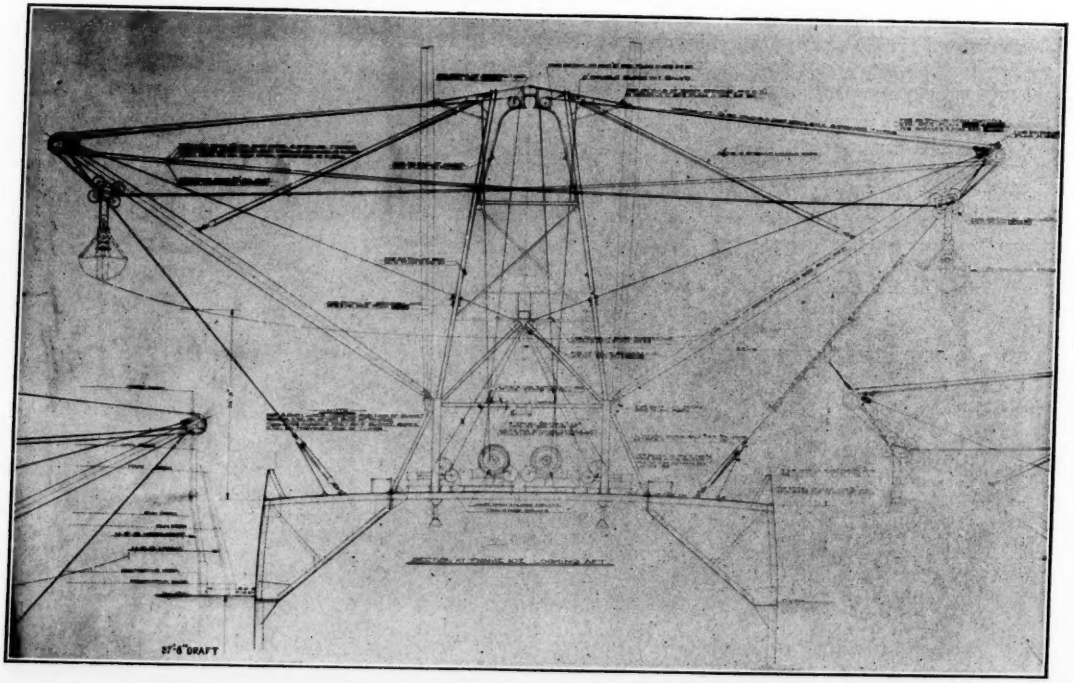


FIG. 4.—RIGGING OF COALING GEAR.

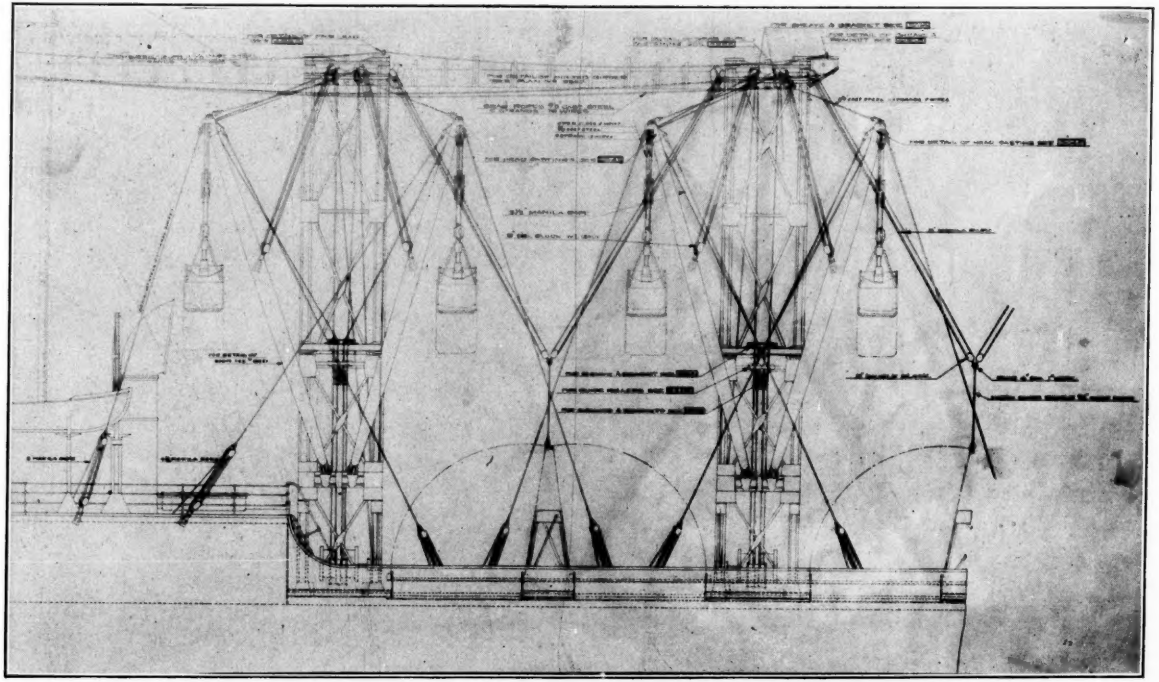


FIG. 5.—RIGGING OF COALING GEAR.

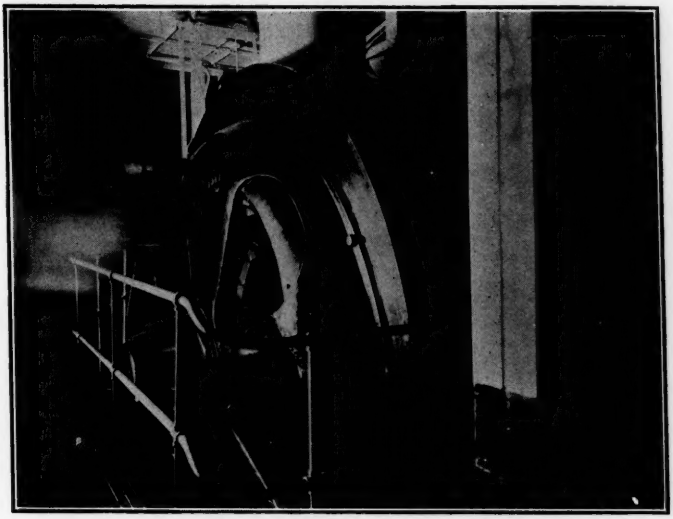


FIG. 6.—MAIN MOTOR, FORWARD END.

FIG. 7.—MAIN MOTORS, AFTER ENDS.

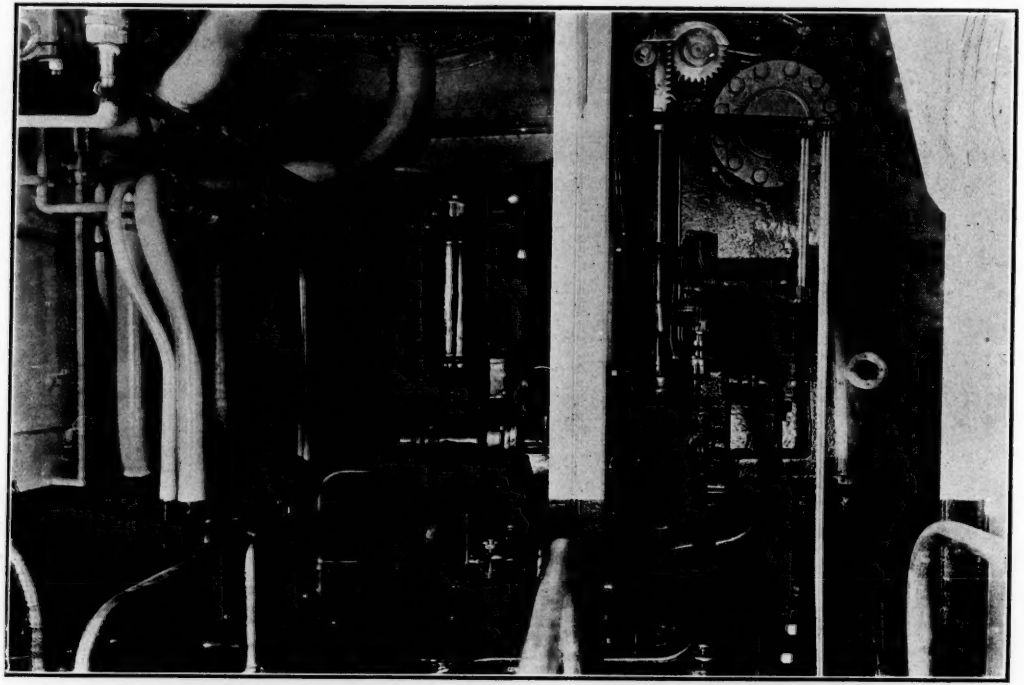


FIG. 8.—GOVERNOR AND GOVERNOR RELAY AND TURBINE VOLUTE PUMP.

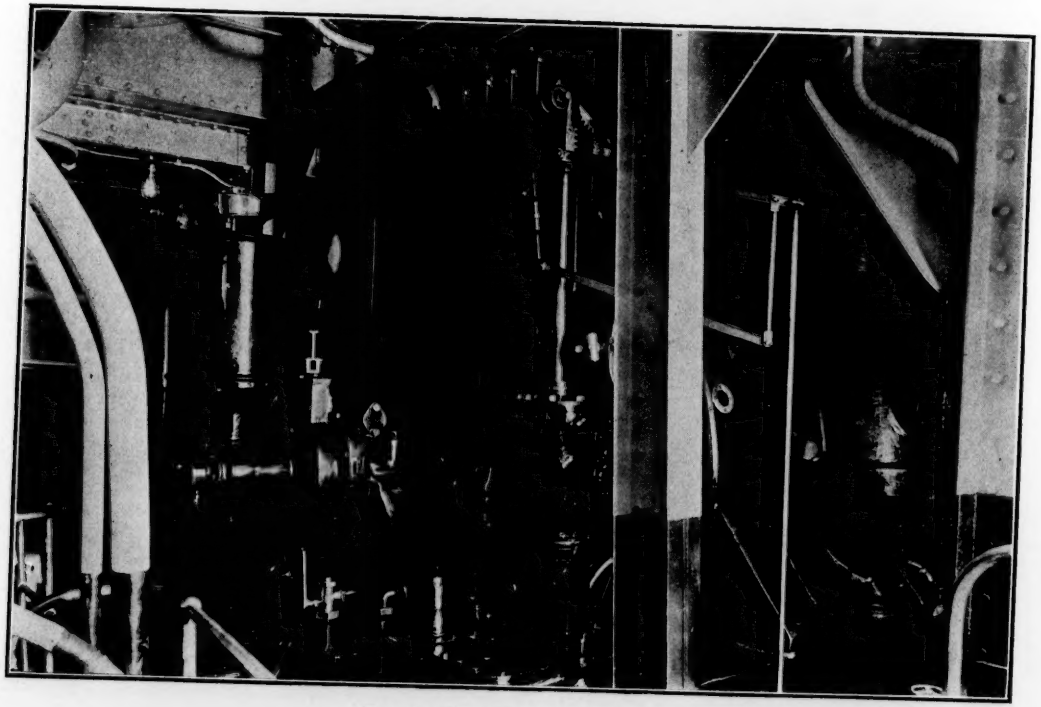


FIG. 9.—TURBINE, AFTER END.

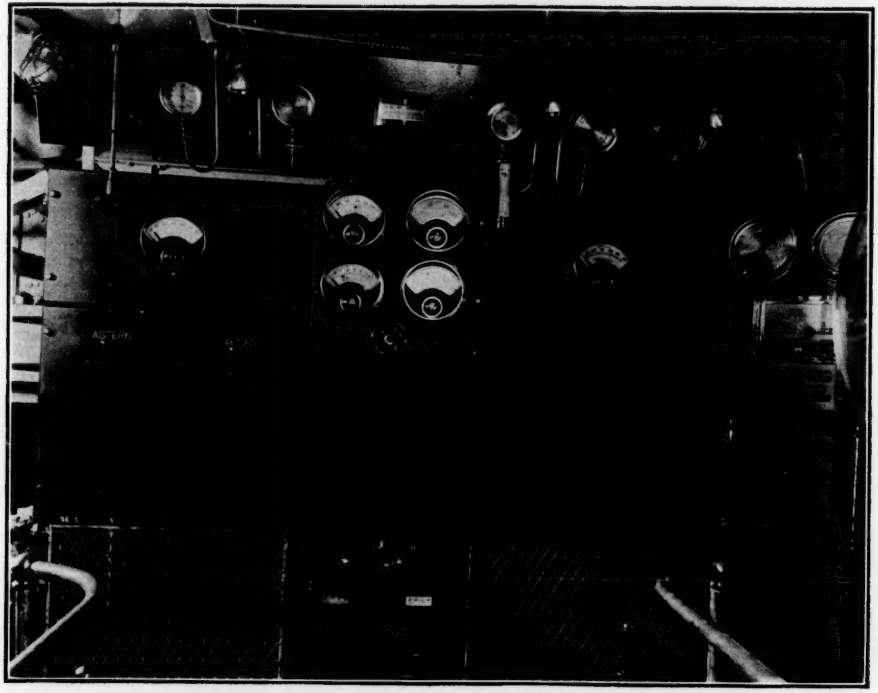


FIG. 10.—MAIN SWITCHBOARD.

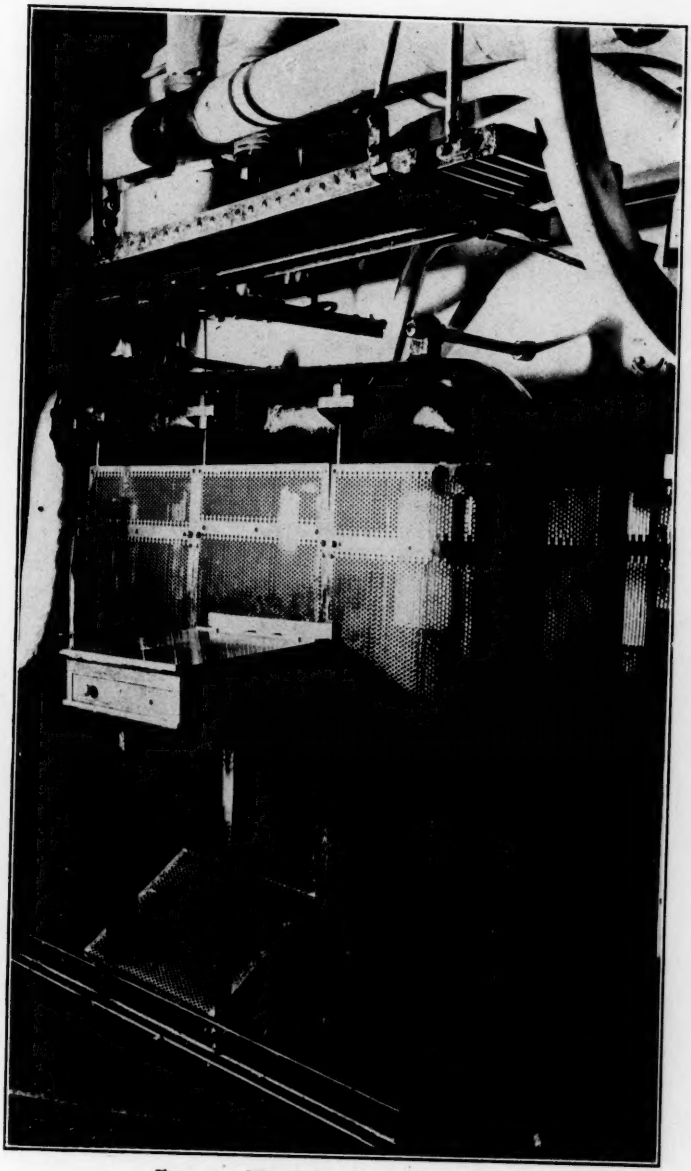


FIG. 11.—WATER-COOLED RHEOSTAT.

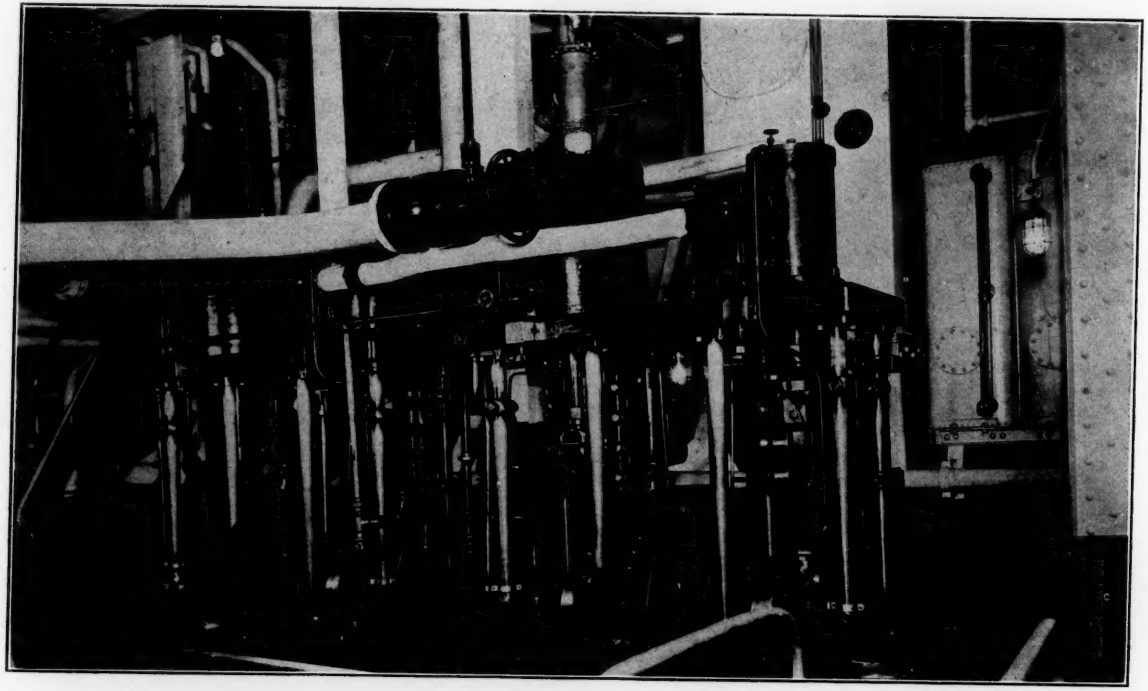


FIG. 12.—DRY-VACUUM PUMPS.

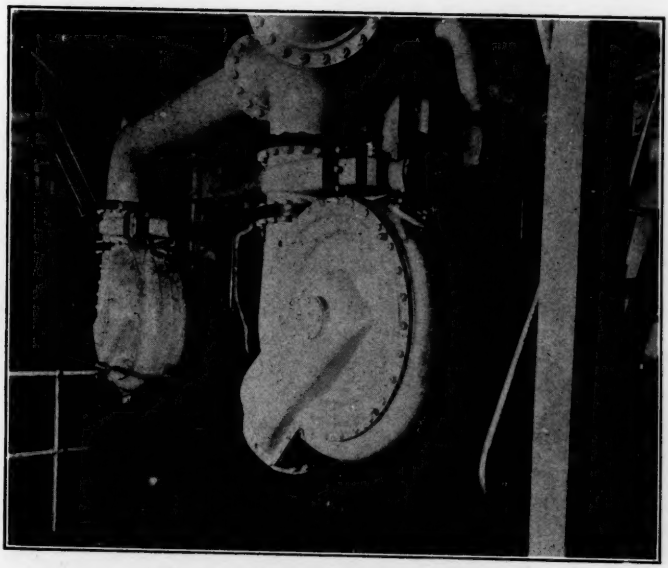


FIG. 13.—MAIN CIRCULATING PUMPS.

FIG. 14.—FIREROOM.

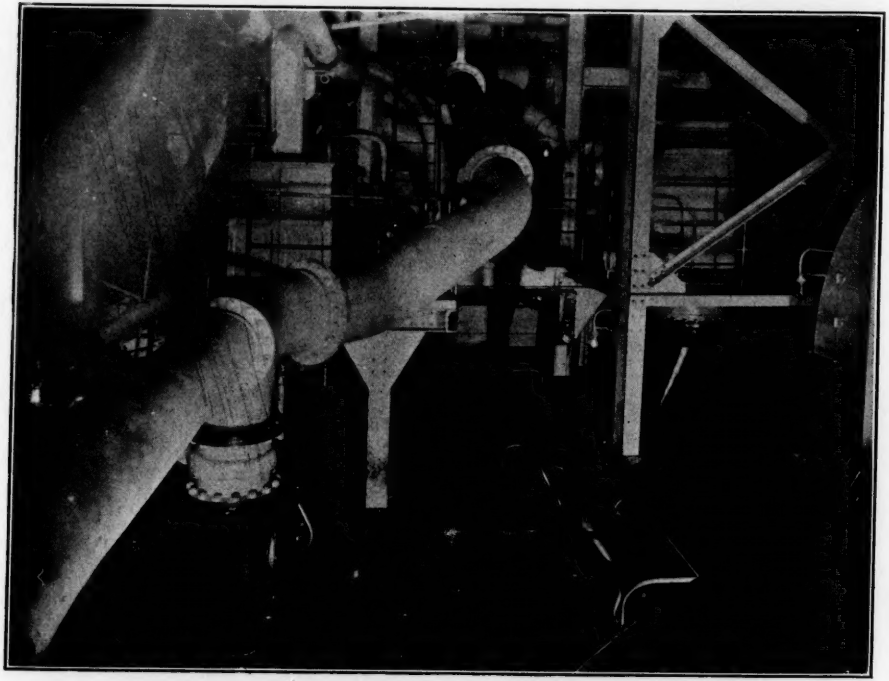


FIG. 15.—ENGINE ROOM, LOOKING AFT ON STARBOARD SIDE.

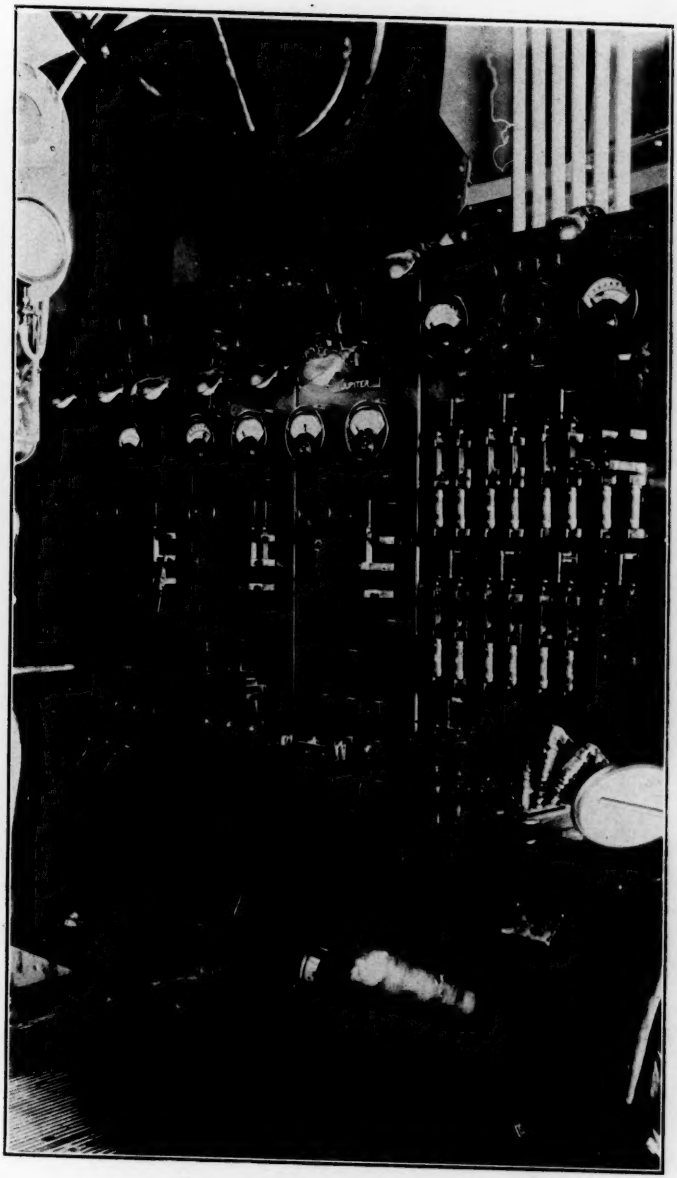
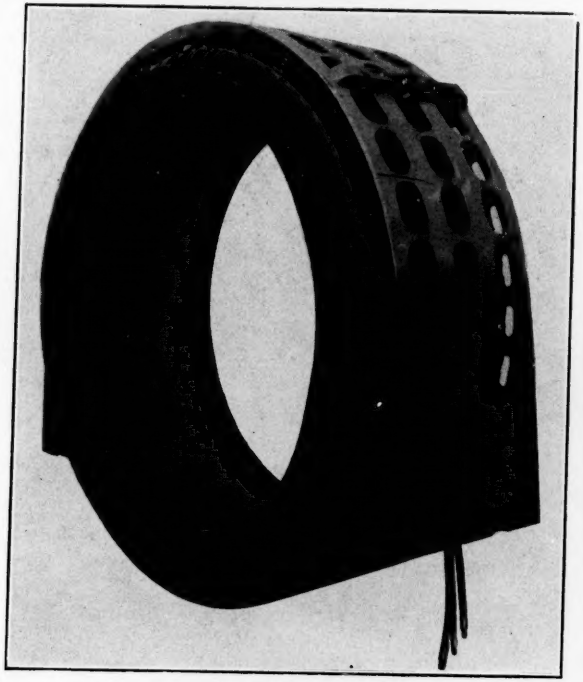
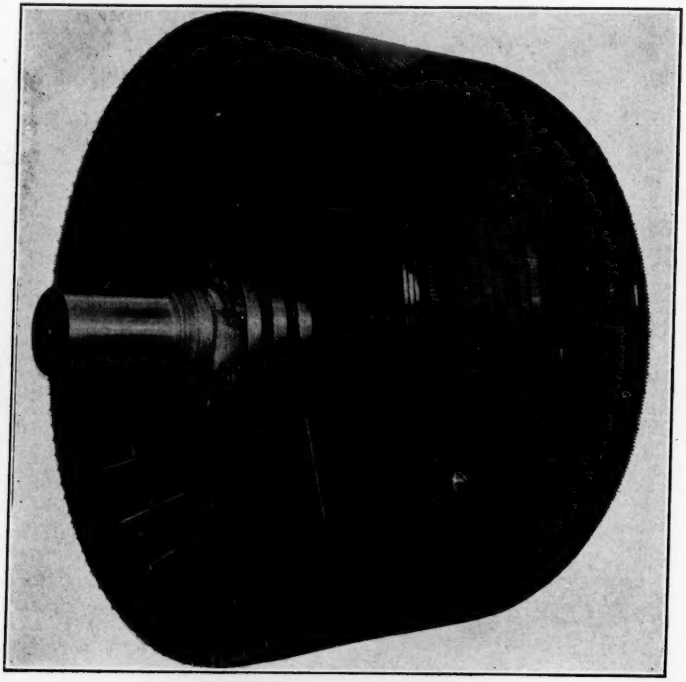


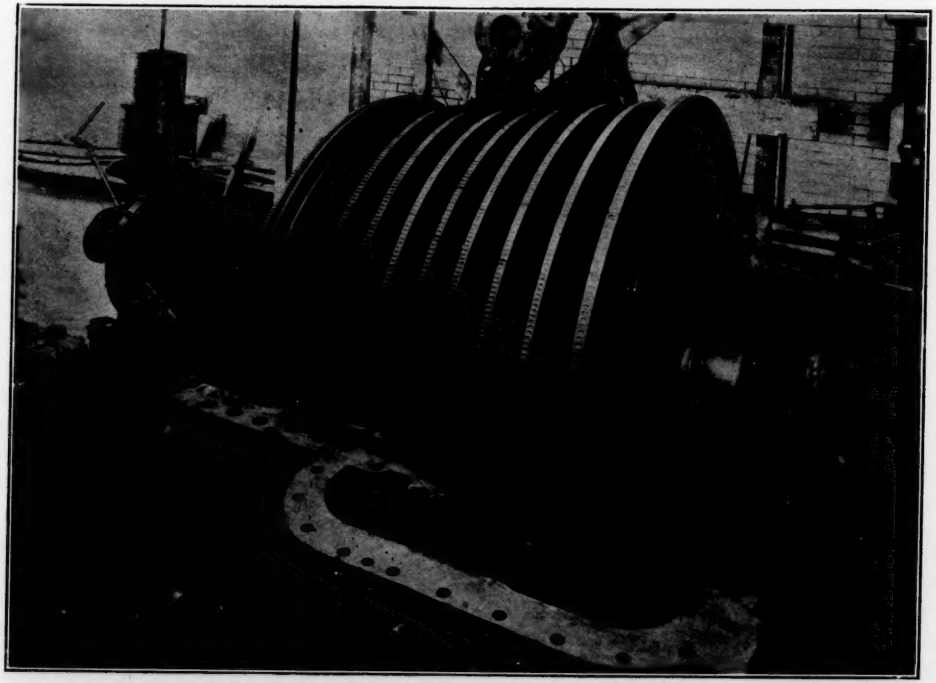
FIG. 16.—EXCITER-SWITCH BOARD.



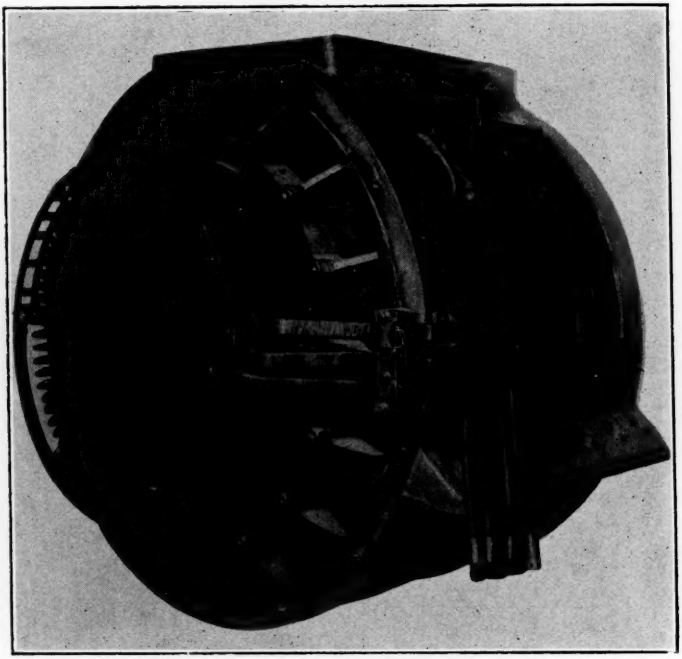
STATOR FOR U. S. COLLIER "JUPITER."



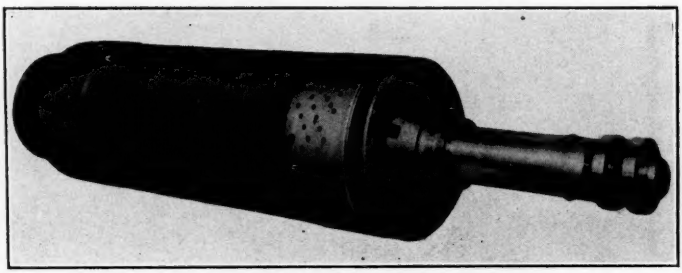
ROTOR FOR U. S. COLLIER "JUPITER."



4,000-KW. NINE-STAGE CURTIS TURBINE FOR U. S. S. COLLIER "JUPITER." MIDDLE BEARING CAP AND TOP INTERMEDIATE HOLDER INTERMEDIATES AND DIAPHRAGM NOZZLES REMOVED.



ARMATURE FOR U. S. S. "JUPITER."



REVOLVING FIELD FOR U. S. S. "JUPITER."

pilot valve and consequently alters the speed which the governor will maintain.

Steam is admitted to the nozzles through eight control valves. The number open at any time is regulated by the governor, as already explained. These valves are of the globe type, and are free on their stems to allow them to easily seat. The stem extends through a stuffing box and is secured to the lower guide plate of the spring which is compressed by an adjusting screw sufficiently to force the stem through the stuffing box and seat the valve. The valve is raised by a lever which has a roller on one end which rides on a cam on the cam shaft.

The thrust bearing consists of a collar on the turbine shaft which works between blocks of cast iron with babbitted faces, supported on the ends of lugs projecting from two discs, one at either end of the bearing. The hole in the block into which the lug projects has a spherical base, thus allowing the blocks to align themselves automatically. The whole bearing assembles in one piece on the shaft and, on its outside surface, has a screw thread which rests in a large nut. On the after end of the thrust block is a worm wheel engaging with a worm, the shaft of which projects through the bearing and has a hand wheel on the end of it. By moving this hand wheel the whole thrust bearing will be moved forward or aft in the large nut and thus change all the clearances on the inside of the turbine. The float in the thrust is set at .017 inch, but can be altered by changing the shims under the after disc.

The throttle valve is a Schutte-Koerting balanced-piston valve with quick-closing attachment, which can be tripped, either by hand or by a trigger on the shaft which flies out when the turbine speed rises above 2,300 r.p.m. The hand trip is also connected by a wire to a hand pull at the operating position at the switchboard.

Steam for the steam seals is supplied from the main steam line through a reducing valve set at 25 pounds pressure per square inch.

There is an auxiliary gage board on the after engine-room bulkhead near the turbine. It has on its face a steam gage, vacuum gage and first-stage pressure gage. This board is for use when starting up the turbine. There is an absolute-vacuum gage connected to the base of the exhaust trunk of the turbine and secured to a stanchion near the turbine.

Generator.

Weight, in tons	35.7
Number of poles	2
Normal volts	2,300
Normal ampères	1,370
Normal frequency	33.2
Normal excitation, in ampères	250
R.p.m.	1,990
Rated capacity, in kilowatts	5,450
Type	A.T.B.
Rotor (solid steel), diameter, inches	36
Rotor core length, inches	60
Number of slots in rotor	36
Width of rotor slot, inch	$\frac{25}{32}$
Depth of rotor slot, inches	04⅛
Air gap, inches	$01\frac{3}{16}$
Number of slots in stator	72
Width of stator slot, inch	00.7
Depth of stator slot, inches	03½
Number of ducts (½ inch wide) in stator	25
Effective length of stator, inches	45.2
Armature connection	Y-2 Circuit.
Number of bars per slot	2
Size of bars....45-inch × 1-inch pressed cable at top of slot and 4 (.225-inch × .5-inch) bar at bottom of slot.	
Resistance of armature winding per phase at 85 degrees C., in ohms	.00311
Field winding consists of nine coils of 15 turns each of .625-inch × .2-inch copper strip.	
Resistance of field winding, at 85 degrees C., in ohms	.389

The generator is totally enclosed, and the rotor has fans on each end which take air in at the bottom of the casing and blow it out through the windings, discharging into a duct on top of the generator casing; this duct leads to the suction to

the forced-draft blowers, so that the heat generated by losses in the iron and copper in the generator is thus passed on to the furnaces of the main boilers. The fans use about 35 kw. at full speed.

The exciting current for the revolving field is supplied to slip rings on the shaft by one of the ship's 35-kw. lighting units.

The three power leads from the generator lead forward under the floor plates, being insulated from the ship by porcelain insulators. One lead goes direct to the two motors and the other two leads to bus bars on the main switchboard.

Motors.

Number	2
Weight (two), tons	76.8
Kind	Induction.
Type	(Definite wound) M.
Number of bearings (each)	2
Diameter of bearings, inches	14
Length of bearings, inches	18
Number of poles	36
Volts	2,300
Rated capacity, in H.P.	2,750
R.p.m. normal	110
Stator winding (rectangular wire)	Y–12 Circuit.
Rotor winding (bars)	Y–4 Circuit.
Outside diameter of stator, inches	120
rotor, inches	110
Inside diameter of rotor, inches	102
Air gap, inch	00.1
Length of punchings between heads, inches	42
Number of ducts (½-inch) in stator	16
rotor	16
slots in rotor	540
stator	432

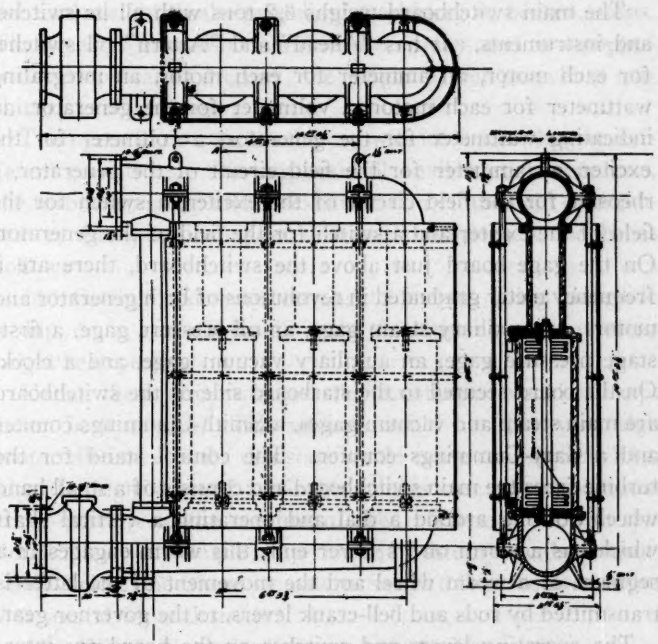
The motor bearings are of the spherical, self-aligning type and are self-oiling, being oiled by rings running in reservoirs in the lower halves of the bearings.

The frames of the motors are of cast steel and are covered by sheet-metal housings which confine and carry away the heated air and deliver it to the suction of the blowers.

Each motor is installed in a watertight pit which can not easily be filled with water from below. However, the motors are situated under the engine-room hatches, so that water from that source would go into the pits, and for this reason the windings are all made waterproof and are intended to give safe running when partially submerged.

The rotor windings are connected to collector rings which are in turn connected to the water-cooled rheostats. These collector rings can be short-circuited by a slider operated by a lever and working on the motor shaft. The short-circuiting device consists of a brass segment under each ring and a corresponding segment on the slider; the segments on the slider are made up of thin brass strips interleaved to form a spring, which will have to be compressed to slip under the solid segments. In addition to these devices, there is an auxiliary device working with each main device. This consists of a carbon block on the solid segment and a brass contact on the slider; the tips of the brass contacts are renewable; these contacts are held in place by flat springs on their backs and will thus be forced into contact before the main contacts are and will leave the carbon blocks after the main contacts have let go; the purpose of these auxiliary contacts is to prevent the main contacts from being burned when opening or closing the circuit.

There are two water-cooled rheostats, one for each motor. The two weigh 5.8 tons. Each one consists of a top header, bottom header, three large porcelain cylinders, three small porcelain cylinders, and three non-inductive resistances. These resistances are made of calorite, and consist of spiral coils laid up on a wooden spindle and having alternate coils connected oppositely from the others so as to make the resistance non-inductive. The large porcelain cylinders rest on rubber gaskets on the bottom header; the resistances go inside these cylinders; a rubber gasket and a brass ring go on top of each large cylinder and the small cylinder sits on top of this; the top header rests on rubber gaskets on the tops of the small



WATER-COOLED RHEOSTAT FOR COLLIER "JUPITER."

cylinders. The rheostats have water entering at the outboard end of the bottom header, passing through the cylinders, and going overboard from the outboard end of the top header; this water is furnished by the main circulating pumps or the sanitary pump. The object of these resistances is to give the motors high torque when backing or when starting from rest and also to keep the current in the circuit within bounds at these times. From an inspection of the speed-torque curve of an induction motor it will be seen that when starting up or backing the torque is very low, and as the speed increases the torque rises to a maximum and then drops to zero at synchronous speed. This maximum torque will always be the same for any given motor, no matter how much resistance is introduced into the rotor, but the speed at which it occurs will vary with the resistance.

The main switchboard weighs 3.2 tons with all its switches and instruments. It has "Ahead" and "Astern" oil switches for each motor, an ammeter for each motor, an integrating wattmeter for each motor, a voltmeter for the generator, an indicating wattmeter for the generator, a voltmeter for the exciter, an ammeter for the field circuit of the generator, a rheostat for the field circuit of the exciter, a switch for the field of the exciter and a switch for the field of the generator. On the gage board just above the switchboard, there are a frequency meter graduated in revolutions of both generator and motors, an auxiliary steam gage, an oil-pressure gage, a first-stage pressure gage, an auxiliary vacuum gage, and a clock. On the board secured to the starboard side of the switchboard are main steam and vacuum gages, a Smith-Cummings counter and a Gary-Cummings counter. The control stand for the turbine faces the main switchboard and consists of a small hand wheel working around a dial and operating a vertical shaft which has a worm on its lower end; this worm engages in a segment of a worm wheel and the movement of the latter is transmitted by rods and bell-crank levers, to the governor gear.

The operating levers and switches on the board are interlocked as follows:

The short-circuiting levers are locked electrically by solenoids which are in series with the field circuit of the generator so that these levers can not be moved while the generator has current in its field circuit; the "resistance out" ends of the levers have been filed so that they can be operated when current is on, but the locks will keep the levers held in this position strongly enough to prevent vibration from moving the levers; the short-circuiting levers and oil switches are locked mechanically so that the oil switches can not be closed when the rheostats are short-circuited; the two oil switches for each motor are mechanically interlocked so that both switches cannot be closed at the same time (that is, the ahead and astern switches of a motor can not be closed at the time time).

A summary of the different weights previously given shows

the total weight of the propelling machinery to be 166.5 tons. The *Cyclops* is a sister ship of the *Jupiter* and is equipped with recriprocating engines; the weight of her propelling machinery is 260.8 tons.

The operation of the machinery will vary according to different conditions. Starting with all auxiliaries in operation, the turbine running, and an exciter cut in on the field of a generator, the operation under different conditions would be as follows:

(1) Getting underway, coming to anchor, going alongside a ship, or, in general, handling the ship where much reversing might be expected.

Under these circumstances, the resistances would be kept in on both motors. This method would not give very high motor efficiency as the rheostats would cause considerable loss; also the highest speed attainable in this case would be about three-quarters of the maximum speed. The operation in this condition is very simple; to go ahead or astern on either motor, simply close the ahead or astern switch; this requires about one second for each motor.

(2) When it is desired to do economical cruising:

It will be necessary to cut the resistances out of the motors; both motors will, of course, be going ahead, as will also the ship; this operation is not performed in answer to a signal from the bridge, but is merely a change of cruising conditions. To carry out this change first open the field switch of the exciter; second, move the control wheel on the dial to very slow speed; third, move both short-circuiting levers so as to short-circuit the rheostats; fourth, close the exciter field switch; fifth, bring the turbine up to the desired speed. The total time required for these operations is about twenty-five seconds; about fifteen of these seconds are required to allow the field circuit to die out sufficiently to allow the short-circuiting levers to be moved.

(3) After having accomplished operation (2), a signal is received to back either one or both engines.

First, open the exciter field switch; second, open the ahead oil switches; third, move the short-circuiting levers so as to put the resistances in both motors; fourth, close the astern oil switches; fifth, close the exciter field switch. The total time required for these operations is about ten seconds. The reason this operation does not require as much time as (2) is that it is not necessary to wait for the generator field circuit to die out before moving the short-circuiting levers.

It will be noted that since the speed of both motors is directly dependent on the speed of the turbine, the speed of the two motors must always be the same unless one of them is entirely stopped.

The above operations have all been tried out on dock trials and the operation of the machinery was satisfactory. Altogether four dock trials have been held.

In connection with the operation of the machinery there are several other conditions that might arise. The rheostats might become disabled, in which case the mechanical interlock between the short-circuiting levers and the oil switches would be disconnected, making it possible to move the oil switches with the rheostats cut out. The ship could then be maneuvered satisfactorily, but it would always be necessary to slow the turbine down to very slow speed before starting up or backing.

Either motor might be disabled, in which case the ship could be propelled with one motor.

In case of failure of the governor the speed could be readily controlled by the throttle itself.

The trials of the ship, together with performance curves of the motors and generator and turbine, will be treated in a separate paper.

STRESSES IN MARINE-ENGINE SHAFTING.

By Ernest N. Janson, Member.

Partial fracturing or total destruction by breakage of sections of shafting in reciprocating-engine ships under circumstances such as would hardly account for the damage having been caused by calculable stresses, together with severe vibration at certain speeds of revolutions, renders evidence of the existence of stresses other than those referred to as calculable stresses. These other stresses, being of an indefinite value and not readily determined, are not considered in the usual methods of figuring shafting.

Stresses in shafting of marine engines may be classified as:

(*a*) "Known" stresses, which are determinable by the ordinary laws of physics and, therefore, may be allowed for.

(*b*) "Unknown" stresses, which are not determinable from the ordinary engine forces but must be established by directly measuring torque by special torsion meters, such as would indicate the fiber displacement of the shaft continuously for one or more revolutions.

In Part I is shown the determination of the "known" stresses caused by the calculable forces, as well as the plotting of curves of combined twisting moments on shafting of actual ships. No attempt has been made to establish values for the "unknown" stresses, but in Part II simple references are made to such of the forces as to which the origin of the "unknown" stresses may be ascribed. Critical speed of revolution is also discussed.

Among the "known" stresses may be enumerated:

(*a*) Stresses due to forces exerted by the pressure of the steam in the various engine cylinders.

(*b*) Stresses due to inertia of moving parts of engine.

(*c*) Stresses due to bending, influenced in the crank shaft by direct action of steam forces and in propeller shafting by weight of propeller and pitching of the ship.

Among the "unknown" stresses are to be found the following:

(*d*) Torsional vibration stresses.

(*e*) Stresses brought on by distortion in alignment of bearings either as a result of wear in the bearings or weakness of hull or in foundations.

(*f*) Stresses resulting from defects in the material or running afoul and reactions of propeller due to pitching.

Stresses under (*e*) and (*f*) are usually allowed for by employing a "safe" stress per square inch of section in the calculations used to determine dimensions. Torsional vibration stresses are not commonly allowed for either as an additional stress or by a reduction in the strain permissible per square inch of material. The additional stress brought on shafting by want of alignment is shown by John H. Macalpine in his paper on "Crank Shafts" (JOURNAL OF AMERICAN SOCIETY OF NAVAL ENGINEERS, November, 1896). Thus, it is shown, where the bearing immediately forward of the after crank is only 0.001 inch out of alignment, which means it offers diminished reaction to the forces subjecting the other bearing to stress, an increase of .3 of one per cent. in the strain occurs beyond what is due to ordinary forces. Augmented stress on the shafting produced by any one cylinder separately due to steam and inertia forces exceeds that due to steam alone by from 12 per cent. to 30 per cent. The combined reaction on the crank shaft in producing maximum twisting moment is, however, not materially changed by inertia forces.

In reciprocating-engine installations the crank shaft is subject to torsion as well as cross bending; thrust shaft to torsion and compression (or tension); line shafting to torsion, compression (or tension) and bending due to weight of shaft;

propeller shaft to torsion, compression (or tension) and bending due to weight of propeller and the shaft itself and action of the water.

In turbine installations similar conditions ensue with respect to line and propeller shafting.

PART I.—KNOWN STRESSES.

STEAM AND INERTIA FORCES.

The twisting moment or turning effort on the shafting at any crank position is equal to corresponding cylinder force P multiplied by the distance between center of crank circle and the point where the connecting rod, or its extension, intersects a line drawn vertically to the center line of engine. Thus if AB, Figure 1, is the center line of the engine through the

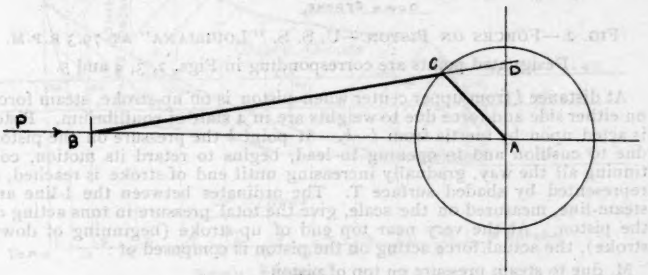


FIG. 1.

cylinder and shaft centers, AC the position of the crank, BC the connecting rod, and AD a line at right angles to AB, then the twisting moment for crank position AC equals P×AD, where P is the cylinder force, or load on the piston.

In Figures 2, 3, 4 and 5 are shown the effective steam forces acting in each of the four cylinders of the U. S. S. *Louisiana* when running at 79.3 r.p.m. The effective steam pressures are taken from actual indicator cards and tabulated in Table I; steam forces for respective crank positions in Table II; acceleration in Table III, and inertia forces in Table IV. Twisting moments are tabulated in Table V.

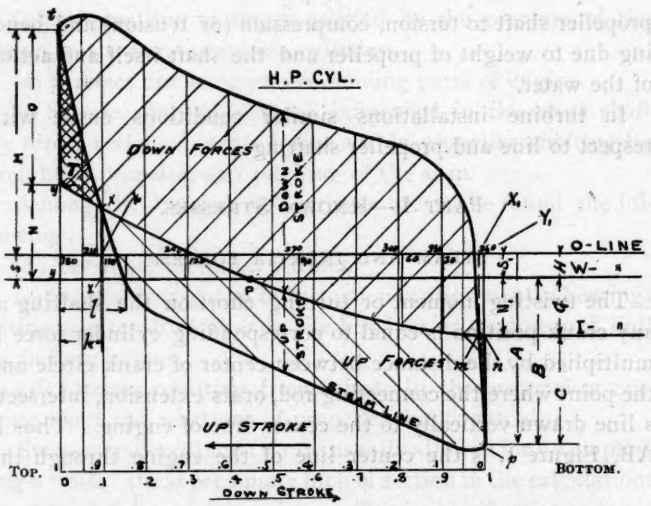


FIG. 2.—FORCES ON PISTON.—U. S. S. "LOUISIANA" AT 79.3 R.P.M.

Designated points are corresponding in Figs. 2, 3, 4 and 5.

At distance l from upper center when piston is on up-stroke, steam forces on either side and force due to weights are in a state of equilibrium. Piston is acted upon by inertia from l—k. At point k the pressure on the piston, due to cushion and to opening to lead, begins to retard its motion, continuing all the way, gradually increasing until end of stroke is reached, as represented by shaded surface T. The ordinates between the I-line and steam-line, measured on the scale, give the total pressure in tons acting on the piston. At the very near top end of up-stroke (beginning of down-stroke), the actual force acting on the piston is composed of:

M, due to steam pressure on top of piston.
+S, weight of moving parts.
—N, inertia of moving parts=O; this must be overcome by forces exerted in other cylinders of the engine.

Similarly near bottom center the actual force on piston is composed of:

A, due to steam pressure on bottom of piston.
—S_1, weight of moving parts.
—N_1, inertia of moving parts=C, the force which must be overcome by other cylinders. The dragging lasts from x to y in up-stroke, and x_1 to y_1 in down-stroke.

The inertia forces in H.P. cylinder are counterbalanced by weight and steam forces at point X (or k). Beyond this point the latter forces act negatively on piston when going up. Point corresponding to X in I.P. and both L.P. cylinders, lies much closer to end of stroke and, therefore, some possibility of shock exists when turning centers in these cylinders. At full power all of these points change materially.

At point P, up-stroke, inertia of moving parts change from minus to plus (*vice versa* on down-stroke), alternately creating retarding and accelerating forces.

The effective down-forces are enclosed by single-sectioned surface $y\ t\ m\ x\ y$ and up-forces by $n\ p\ x$.

I.P. CYL.

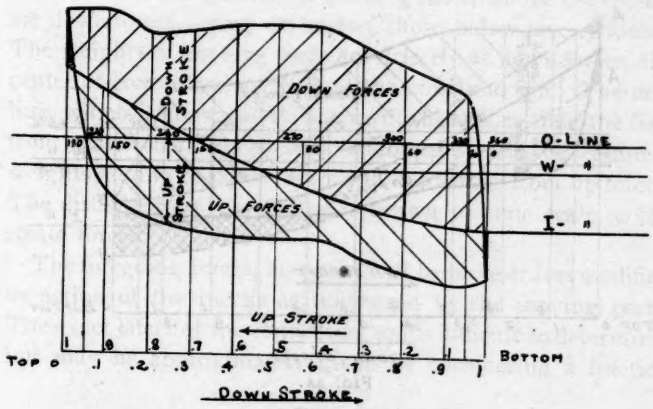


FIG. 3.

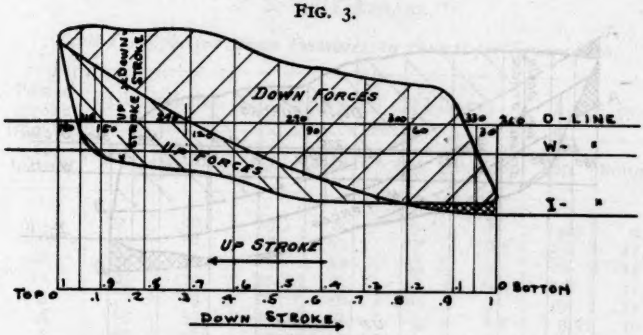


FIG. 4.

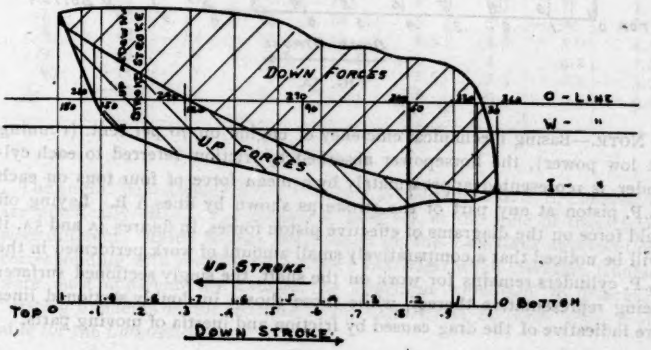


FIG. 5.

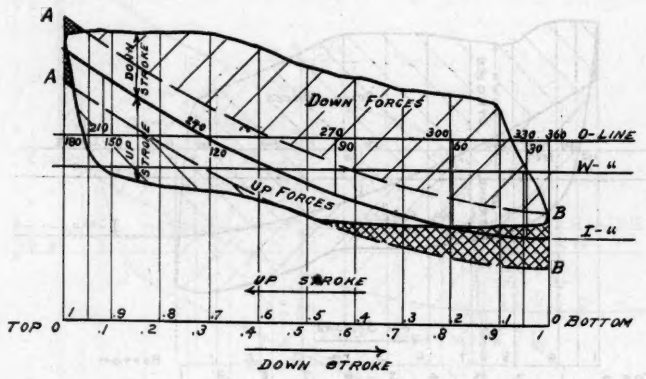


FIG. 4A.

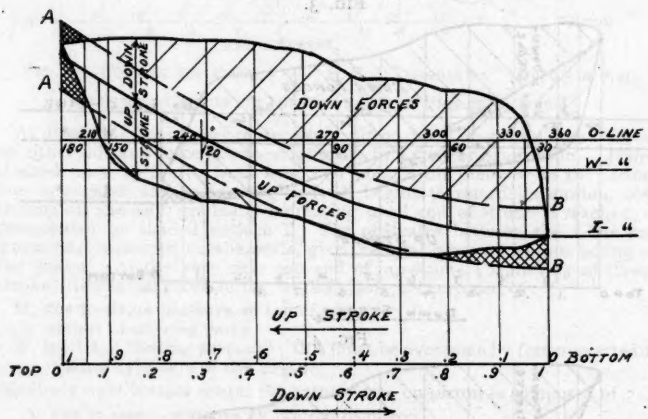


FIG. 5A.

NOTE.—Basing mechanical efficiency of engine on 70 per cent. (running at low power), the horsepower absorbed by friction, referred to each cylinder, is represented approximately by a mean force of four tons on each L.P. piston at any part of the stroke as shown by lines A B. Laying off said force on the diagrams of effective piston forces, in figures 4A and 5A, it will be noticed that a comparatively small amount of work performed in the L.P. cylinders remains for work on the shaft, the singly sectioned surfaces being representative thereof, while those shown in doubly sectioned lines are indicative of the drag caused by friction and inertia of moving parts.

Ordinates in Figures 2, 3, 4 and 5, shown above the O-line, are down-forces acting on piston, those below are up-forces. The weights of moving parts act directly as down-forces, the center of concentration being at the crosshead pin. The new line, which is shown as W-line in the figures, is then the line from which both down and up-forces should be counted, weights adding to down-forces and detracting from up-forces. The distance from the O-line is drawn to same scale as the steam forces.

The foregoing forces, however, will be more or less modified by action of the inertia as influenced by the moving parts. The exact effect of the connecting rod is difficult to determine, but may be approximately given by considering a fraction

U. S. S. "LOUISIANA."

Table I.—Effective Steam Pressures, in Pounds per Square Inch.

Part of stroke from top or bottom.	H.P. cylinder,		I.P. cylinder.		F.L.P. cyl.		A.L.P. cyl.	
	Top.	Bottom.	Top.	Bottom.	Top.	Bottom.	Top.	Bottom.
0	90	80	19.3	21	9.5	8	9.5	9.5
0.05	95	82	19	22	10	8.7	10	11
.1	94	79	19	22	10	9	10	11
.2	83	70	15.5	20	10	9.2	10	11.5
.3	72	63	16	18	10	9	10	11.5
.4	65	55	17	15	9	8.5	9.5	10
.5	59	48	17	15	7	8	8.5	8.
.6	53	41	17	15	6	6.5	7	7
.7	48	31	13	14	5	5.5	6	6
.8	44	24	11	12	4.5	4.8	5.0	4.5
.9	35	— 2	8.5	8.5	3	4	4.2	1.8
.95	21	— 7	7	2.5	1.5	1.5	2.2	— 3.2
1.	—80	—90	—21	—19.3	— 8	—9.5	— 9.5	— 9.5

Remarks.

The engine installations of the U. S. S. *Louisiana* and U. S. S. *Connecticut* are practically alike. The propellers, however, at the time of these trials were different. Cards having been taken on the *Louisiana* at revolutions corresponding with revolutions on the *Connecticut* when vibration troubles were most apparent, the data of the *Louisiana* were used to determine twisting moments on the shafting of the *Connecticut*, no cards being available for the *Connecticut*.

Bottom pressures create up-forces, corresponding to up-stroke.

Top pressures create down-forces, corresponding to down-stroke.

Steam force on piston in tons $= \frac{\text{Area of cylinder in square inches}}{2{,}240} \times$ pressure $= C \times$ pressure.

Pressures given are from cards taken March 12, 1910, U. S. S. *Louisiana*.

Length of connecting rod $= l = 8'0''$; $n = \frac{l}{r} = 4$;

Length of crank $= r = 2'0''$.

Cylinder.	Weight (pounds).			Mass.	
	Piston, piston rod and cross-head. a	Connecting rod. b	Total. w	$a + .38b$.	m
H.P.....	4,000	4,875	8,875	5,856	181
I.P.....	4,300	4,700	9,200	6,087	189
F.L.P.....	4,525	4,550	9,075	6,264	194
A.L.P.....	4,370	4,540	8,910	6,080	189

$$\frac{\text{Cylinder area in sq. ins.}}{2{,}240} = \text{constant} = C.$$

Cylinder.	C		Diameters.	Stroke $= d$.	R.p.m.	Diameter of piston rod.	Radius crank $= r$.
	Top.	Bottom.					
H.P.....	.37	.35	32.5″	48″	79.3	7.25″	2′
I.P.....	1.00	.96	53.0″	48″	79.3	7.25″	2′
F.L.P.....	1.3	1.28	61.0″	48″	79.3	7.25″	2′
A.L.P.....	1.3	1.28	61.0″	48″	79.3	7.55″	2′

$$\text{Mass} = m = \frac{\text{Weight of purely rec. parts} + .38 \text{ weight of connecting rod}}{32.2}.$$

$\frac{5{,}856}{32.2} = 181$ — H.P. cyl.

$\frac{6{,}087}{32.2} = 189$ — I.P. cyl.

$\frac{6{,}264}{32.2} = 191$ — F.L.P. cyl.

$\frac{6{,}080}{32.2} = 189$ — A.L.P. cyl.

Table II.—Effective Steam Forces on Pistons (in Tons).

Part of stroke.	H.P. cylinder.				I.P. cylinder.				L.P. cylinders.							
	Pressure.		Force.		Pressure.		Force.		Pressure.				F.L.P. Cyl.		A.L.P. Cyl.	
									F.L.P.		A.L.P.					
From top or bottom.	Top.	Bottom.	Top or down force.	Bottom or up force.	Top.	Bottom.	Top or down force.	Bottom or up force.	Top.	Bottom.	Top.	Bottom.	Top or down force.	Bottom or up force.	Top or down force.	Bottom or up force.
0	90	80	33.3	28.0	19.3	21	19.0	20.15	9.5	8 *	9.5	9.5	12.35	10.4	12.35	12.35
1/20	95	82	35.1	28.7	19.0	22	19.0	21.12	10	8.7	10	11	13.0	11.13	13.0	14.08
.1	94	79	34.7	27.6	19.0	22	19.0	21.12	10	9.0	10	11	13.0	11.5	13.0	14.08
.2	83	70	30.7	24.5	15.5	20	15.5	19.2	10	9.2	10	11.5	13.0	11.77	13.0	14.7
.3	72	63	26.6	22.0	16.0	18	16.0	17.28	10	9.0	10	11.5	13.0	11.5	13.0	14.7
.4	65	55	24.05	19.2	17.0	15	17.0	14.4	9	8.5	9 5	0.0	11.7	10.87	12.3	12.8
.5	59	48	21.8	16.8	17.0	15	17.0	14.4	7	8.0	8.5	8.0	9.1	10.24	11.05	10.24
.6	53	41	19.6	14.35	17.0	15	17.0	14.4	6	6.5	7.0	7.0	7.8	8.32	8.45	8.96
.7	48	31	17.7	10.85	13.0	14	13.85	13.4	5	5.5	6.0	6.0	6.5	7.04	7.8	7.68
.8	44	24	16.3	8.40	11.0	12	11.0	11.5	4.5	4.8	5.0	4.5	5.85	6.14	6.5	5.76
.9	35	—2	12.9	—.7	8.5	8.5	8.5	8.16	2.5	4.0	4.2	1.8	3.25	5.12	5.46	2.3
19/20	21	—7	7.7	—2.45	7.0	2.5	7.0	2.4	—2.8	1.5	2.2	—2.0	—3.64	1.92	2.86	—4.09
1.	—80	—90	—28.0	—33.3	—21.0	—19.3	—20.15	—19.0	—8	—9.5	—9.5	—9.5	—10.4	—12.35	—12.15	—12.35

Table III.—Values of: $f = \omega^2 r\left(\text{Cos}\,\theta - \frac{\text{Cos}\,2\theta}{n}\right)$.

θ.	Cos θ.	Cos 2θ.	$\frac{\text{Cos}\,2\theta}{n}$.	$\text{Cos}\,\theta - \frac{\text{Cos}\,2\theta}{n}$.	$\omega^2 r$.	$\omega^2 r\left(\text{Cos}\,\theta - \frac{\text{Cos}\,2\theta}{n}\right)$.
0	+1.000	+1.0	+.25	+.75	138	+103.5
30	+.866	+.5	+.125	+.741	138	+102.3
60	+.5	−.5	−.125	+.625	138	+86.2
90	0.0	−1.0	−.25	+.25	138	+34.5
120	−.5	−.5	−.125	−.375	138	−51.75
150	−.866	+.5	+.125	−.991	138	−136.8
180	−1.000	+1.0	+.25	−1.25	138	−172.5
210	−.866	+.5	+.125	−.991	138	−136.8
240	−.5	−.5	−.125	−.375	138	−51.75
270	0.0	−1.0	+.25	+.25	138	+34.5
300	+.5	−.5	−.125	+.625	138	+86.26
330	+.866	+.5	+.125	+.741	138	+102.3
360	+1.0	+1.0	+.25	+.75	138	+103.5

Remarks.

f = acceleration in feet per second per second.

ω = angular velocity of crank shaft in radians per second = $\frac{\pi \times 79.3}{30} = 8.31$; $\omega^2 = 69$.

r = crank radius in feet.

n = length of connecting rod divided by crank radius.

θ = crank angle from H.P. cylinder bottom dead center. (B.d.c.)

Table IV.—Inertia Forces (Tons).

θ	M				f	Inertia forces I (tons).			
Angle turned by crank from H.P. Cyl. *B.d.c.*	H.P. cylinder.	I.P. cylinder.	F.L.P. cylinder.	A.L.P. cylinder.		H.P. Cyl. Down or up-stroke.	I.P. Cyl. Down or up-stroke.	F.L.P. Cyl. Down or up-stroke.	A.L.P. Cyl. Down or up-stroke.
0	181	189	194	189	+103.5	+8 36	+8.73	+8.96	+8.73
30	181	189	194	189	+102.3	+8.24	+8.61	+8.83	+8.61
60	181	189	194	189	+86.2	+6.96	+7.27	+7.46	+7.27
90	181	189	194	189	+34.5	+2.78	+2.91	+2.99	+2.91
120	181	189	194	189	−51.75	−4.12	−4.30	−4.41	−4.30
150	181	189	194	189	−136.8	−11.05	−11.54	−11.85	−11.54
180	181	189	194	189	−172.5	−13.9	−14.52	−14.9	−14.52
210	181	189	194	189	−136.8	−11.5	−11.54	−11.85	−11.54
240	181	189	194	189	−51.75	−4.12	−4.30	−4.41	−4.30
270	181	189	194	189	+34.5	+2.78	+2.91	+2.99	+2.91
300	181	189	194	189	+86.2	+6.96	+7.27	+7.46	+7.27
330	181	189	194	189	+102.3	+8.24	+8.61	+8.83	+8.61
360	181	189	194	189	+103.5	+8.36	+8.73	+8.96	+8.73

Data.

Angular velocity of crank shaft in radians per second $= \omega = \frac{\pi \times R}{30}$, where R = revolutions per minute. Inertia forces in tons $= f \frac{m}{2,240}$.

Table V.—Twisting Moments (Foot Tons).

Angle turned by crank with reference to H.P. cylinder bottom, dead center.	Length of arm creating moment.	H.P. cylinder.		I.P. cylinder.		F.L.P. cylinder.		A.L.P. cylinder.	
		Force.	Moment.	Force.	Moment.	Force.	Moment.	Force.	Moment.
0	0.00	+16.00	0.00	+7.00	0.00	−2.6	0.00	− 0.5	0.00
30	0.78	+17.00	+13.2	+8.2	+6.39	−1.5	−1.17	+ 1.5	+1.17
60	1.52	+14.00	+21.3	+8.0	+12.16	−0.3	−0.45	+ 3.5	+5.32
90	2.00	+12.2	+24.4	+7.5	+15.0	+3.5	+7.0	+ 4.4	+8.8
120	1.95	+11.2	+21.8	+13.5	+26.3	+7.0	+13.65	+ 8.2	+16.0
150	1.22	−2.1	−2.56	+14.0	+17.8	+12.0	+14.64	+ 7.0	+8.54
180	0.00	−23.1	0.00	−8.5	0.00	−1.5	0.00	+ 1.5	0.00
210	1.22	+27.7	+33.8	+11.7	+14.27	+5.5	+6.71	+ 5.4	+6.58
240	1.95	+26.3	+51.28	+15.8	+30.8	+13.2	+25.74	+12.6	+24.57
270	2.00	+26.5	+53.0	+23.7	+47.4	+15.5	+31.0	+17.0	+34.0
300	1.52	+26.5	+40.2	+22.3	+33.9	+17.0	+25.84	+17.9	+27.2
330	0.78	+19.8	+15.45	+19.5	+15.2	+8.9	+6.94	+14.5	+11.3
360	0.00	−16.00	0.00	−7.0	0.00	+2.6	0.00	+ 0.5	0.00

Remarks.—1. Length of arm creating moment is in feet. 2. Cylinder forces are in tons. 3. Moments are in foot tons.

of its weight moving with the purely reciprocating parts. This fraction is the weight of the rod multiplied by the ratio of distance of its center of gravity to center of crank pin and the length of the rod between centers. In the example before us this ratio is .38.

If for any crank position the acceleration of reciprocating parts, including connecting rod, piston, piston rod and crosshead, is f feet per second per second, the force necessary to create this acceleration is $f \times m$, where m is the mass of reciprocating parts as given in column of remarks, Table I. The inertia forces of slow-running engines are of minor significance, but enter as an important factor in engines of high piston speed, although not as altering the magnitude of mean or combined twisting moments.

INERTIA OF MOVING PARTS.

(*a*) Acceleration f is a maximum at the end of up-stroke.

(*b*) Force due to inertia at end of stroke should be absorbed by compression and opening to lead. By judiciously choosing the points of release, cushion and lead, a state of complete absorption of acceleration may be obtained.

(*c*) Force necessary to overcome inertia of moving parts $= f \times m$, value of f with due consideration to crank position.

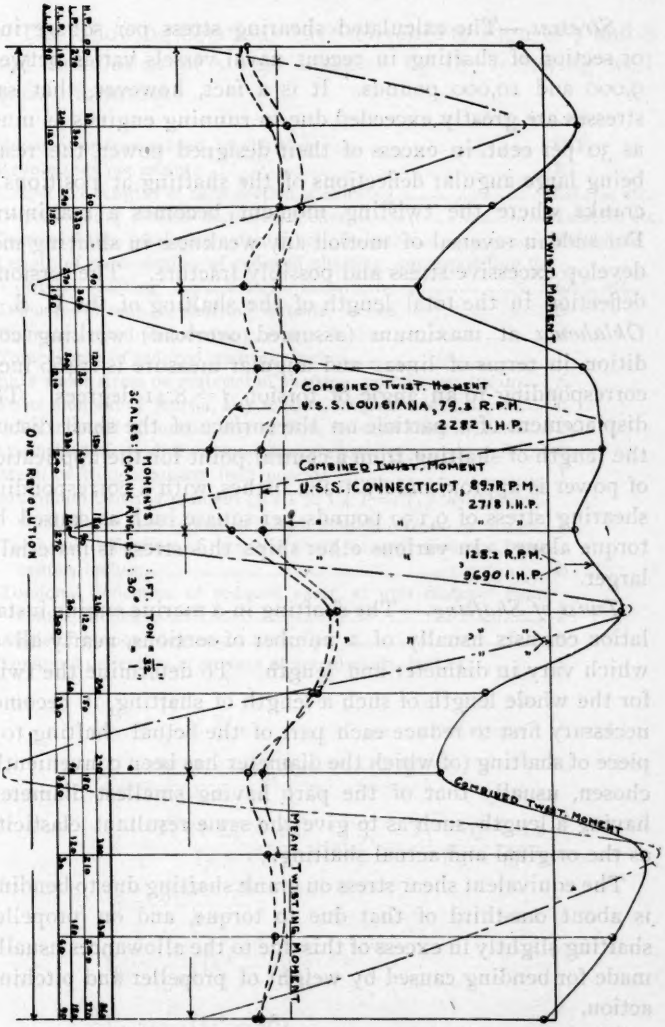
(*d*) Effective force on piston for any crank position is that due to steam and dead weight of moving parts, minus or plus the inertia force—minus where the inertia is a retarding force, as is the case in the down-stroke to a point about .45 stroke and plus for the remainder of stroke, and plus in up-stroke to a point about .55 stroke for the remainder of stroke (see Figures 2–5).

(*h*) Inertia forces, I-line, are offset from the W-line, due regard being had to direction and sign.

COMBINED TWISTING MOMENT.

The twisting moment on the shafting as a result of the combined action of the cranks is resisted by the screw propeller and the friction throughout the bearings. In Figure 6 are shown three curves representing the combined twisting-moment curves of the U. S. S. *Connecticut* at 128.2 r.p.m., which is equivalent to full power conditions; the combined twisting-moment curve of the same ship at cruising speed of about 13 knots, and also of the *Louisiana* at approximately 12¼ knots; the revolutions corresponding to latter speeds being, respectively, 89 and 79.3.

Twisting moments for the last-named condition and ship are figured out in Table V and are transposed to scale as shown in Figure 6. The crank sequence is laid off on the abscissa corresponding to the order existing in the engine. Moments are in foot tons offset on ordinates to scale chosen. It will be noted from the curves that the maximum twisting moment at full power is only 2.3 times that at one-quarter



CURVES OF TWIST. MOMENTS ON CRANK SHAFTS.

FIG. 6.

power, and, on the whole, *proportionately* to the power, less strain is developed on the shafting when running full than when running slow.

Stresses.—The calculated shearing stress per square inch or section of shafting in recent naval vessels varies between 9,000 and 10,000 pounds. It is a fact, however, that said stresses are greatly exceeded due to running engines as much as 30 per cent. in excess of their designed power, the result being large angular deflections of the shafting at positions of cranks where the twisting moment becomes a maximum. For sudden reversal of motion any weakness in shafting may develop excessive stress and possibly fracture. The torsional deflection in the total length of the shafting of the U. S. S. *Oklahoma* at maximum (assumed overload) working condition in terms of linear and angular measure is .1466 inch, corresponding to an angle of torsion $\beta = 8.41$ degrees. The displacement of a particle on the surface of the shaft distant the length of shafting from a central point for the application of power is approximately 1.282 inches, with a corresponding shearing stress of 9,150 pounds per square inch as caused by torque alone. In various other ships this stress is materially larger.

Twist of Shafting.—The shafting in a marine-engine installation consists usually of a number of sections, nearly all of which vary in diameter and length. To determine the twist for the whole length of such a length of shafting, it becomes necessary first to reduce each part of the actual shafting to a piece of shafting (of which the diameter has been conveniently chosen, usually that of the part having smallest diameter) having a length such as to give the same resultant elasticity as the original and actual shafting.

The equivalent shear stress on crank shafting due to bending is about one-third of that due to torque, and on propeller shafting slightly in excess of this due to the allowances usually made for bending caused by weight of propeller and pitching action.

The surface displacement, or torsional deflection, is due to torque alone, and this deflection, therefore, is determined from the maximum twisting moment acting on the reduced shafting without consideration to bending moment.

The following notations have reference to Figures 7 and 8, and calculation of stress is shown by the following well-known formulae:

Horsepower transmitted by shafting	H.P.
Revolutions per minute	R.
Respective lengths of each section of shafting	$L_0L_1L_2$, etc.
Corresponding outside diameter, inches	$D_0D_1D_2$, etc.
Corresponding inside diameter, if hollow, inches	$d_0d_1d_2$, etc.
Length of each section of reduced shafting, corresponding to original shafting	$l_0l_1l_2$, etc.
Diameter of reduced shafting, outside, inches	D
Diameter of reduced shafting, inside, inches	d
Total length of reduced shafting, inches	L
Skin shear stress on material of shafting, pounds per sq. in	f_s
Polar moment of inertia, any section, original shaft	I_p
Polar moment of inertia, any section, reduced shaft	I^1_p
Coefficient of rigidity, or modulus of elasticity	G
Mean twisting moment, inch pounds	T
Maximum twisting moment (1.2 T to 1.4 T = cT, c being a constant due to type of engine), inch pounds	T_1
Torsional deflection of original shaft, at unit distance from center, inches	Z
Torsional deflection of reduced shaft, at unit distance from center, inches	Z^1
Angle of torsion, degrees	β
Torsional deflection at surface of actual shaft, inches	F

$$F = \frac{D}{2} \times Z^1;$$

$$T_1 = \frac{\text{H.P.} \times 63{,}000 \times c \times T}{R};$$

$$Z = \frac{T_1 \times L_0 \times 12}{I_p \times G} \text{ and } Z^1 = \frac{T_1 \times l_0 \times 12}{I^1_p \times G};$$

$$\beta = \frac{360 \times Z^1}{2\pi};$$

$$I_p = \frac{\pi}{32}(D_0^4 - d_0^4);$$

$$I^1_p = \frac{\pi}{32}(D^4 - d^4).$$

Owing to the fact that the resultant elasticity of the reduced shaft is assumed to be the same as that of the original, we have.

$$Z = Z^1$$

$$l_0 \times I_p = L_0 \times I^1_p;$$

$$\frac{L_0}{l_0} = \frac{I_p}{I^1_p} = \frac{D_0^4 - d_0^4}{D^4 - d^4};$$

$$l_0 = \frac{L_0 (D^4 - d^4)}{D_0^4 - d_0^4};$$

$$L = l_0 + l_1 + l_2 + l_3 + \ldots$$

In the example which follows, the quantities established by the foregoing formulas, worked out for the shafting of the U. S. S. *Oklahoma*, see Figures 7 and 8, are:

$$I^1_p = \frac{\pi}{32}(17.5^4 - 8.75^4) = 8{,}600;$$

$$Z^1 = \frac{9{,}000{,}000 \times 145.87 \times 12}{8.600 \times 12{,}500{,}000} = .1466;$$

$$\beta = \frac{360 \times .1466}{2\pi} = 8.41 \text{ degrees};$$

$$F = \frac{17.5}{2} \times .1466 = 1.282 \text{ inches.}$$

The shearing stress corresponding to deflection F from

$$\frac{F}{L} = \frac{f_s}{G};$$

$$f_s = \frac{1.282 \times 12{,}500{,}000}{145.87 \times 12} = 9{,}150 \text{ pounds.}$$

The shear stress on shafting in steam turbine-driven ships varies between 5,500 pounds and 6,500 pounds per square inch of material. Should latter be made maximum allowance on shafting of U. S. S. *Oklahoma*, we get:

$$F = .858 \text{ inch};$$

$$Z^1 = .0971 \text{ inch};$$

$$\beta = 5.57 \text{ degrees};$$

$$D = 18.16 \text{ inches} \left(\text{retaining } \frac{D}{d} = \frac{1}{2} \right);$$

or an average increase of a little more than $\frac{5}{8}$ inch on the outer diameter throughout the shafting. Note that with a shearing stress of 6,500 pounds per square inch allowed, the total stress, inclusive of that due to bending, would be approximately 8,700 pounds, which is considerably less than usually allowed.

FIG. 7.

Dimensions corresponding to length, outer and inner diameter in actual and reduced shafting shown in above sketch, are as follows:

L_0=49.0′	L_1= 5.8′	L_2=55.85′	L_3=1.75′	L_4=16.8′	$L_5+L_9+L_{11}$=2.0′	L_6+L_8=11.1′	L_7=3.7′	L_{10}=13.8′	L_{12}=18.0′	L_{13}=10.8′
D_0=18.0″	D_1=24.0″	D_2=18.0″	33.0″	17.5″	33.0″	17.5″	27.5″	17.5″	18.7″	18.7″
d_0=9.0″	d_1= 8.75″	d_2= 9.0″	8.75″	8.75″	8.75″	8.75″	8.75″	8.75″	10.0″	10.0″
l_0=42.9′	l_1= 1.54′	l_2=48.85′	l_3=0.97′	l_4=16.8′	$l_5+l_9+l_{11}$=1.1′	l_6+l_8=11.1′	l_7=0.56′	l_{10}=13.8′	l_{12}=13.75′	l_{13}= 8.3′

L=145.87′; D=17.5″; d=8.75″.

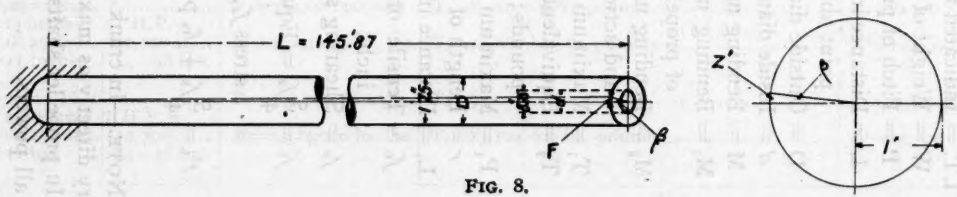


FIG. 8.

SYNOPSIS OF SHAFTING CALCULATIONS.

R.p.m. = Revolutions per minute;
S = Speed of ship in knots;
I.H.P. = Indicated horsepower;
I.T. = Indicated thrust;
W = Weight of propeller, in pounds;
P = Pitch of propeller, in feet;
L = Distance in inches from center of propeller hub to a point about 3 inches within strut bearing;
D = Outside diameter of shaft, inches;
d = Inside diameter of shaft, inches;
M = Bending moment on crank shaft, inch pounds;
M_1 = Bending moment on propeller shaft due to weight of propeller, inch pounds;
M_2 = Bending moment on propeller shaft due to pitching and action of water, inch pounds;
T_1 = Maximum twisting moment, inch pounds;
T_2 = Equivalent maximum twisting moment, inch pounds;
P_1 = Maximum turning force, pounds;
r = Length of crank, in inches;
L_1 = Distance in inches over crank arms + .2 D;
f_c = Tensile or compressive stress, pounds per square inch;
f_s = Shearing stress, pounds per square inch.

$f_t = \frac{5}{4} f_s$ = Equivalent tensile stress, due to shearing stress f_s, pounds per square inch;

$f'_t = \frac{5}{4} f_s + f_c$, pounds per square inch.

NOTE.—In crank shafts bending moments are assumed to vary directly as maximum turning force.

In propeller shafts bending moments are assumed constant at all powers.

U. S. S. "DELAWARE."

Table VI.—Crank Shaft.

R.p.m.....	I.H.P	$P_1=\frac{T_1}{r}$; $M=\frac{P_1\times L_1}{8}$ ..	*$T_1=\frac{\text{I.H.P.}\times 88{,}200}{\text{r.p.m.}}$	$f_s=\frac{5.1\times T_2\times D}{D^4-d^4}$.
r, D, d.....	L_1	.....	$T_2=M+\sqrt{M^2+T_1^2}$	$f_t^1=\frac{5}{4}f_s$.
R.p.m.=100 ...	.....	P_1=212,500 pounds ..	T_1=5,100,000 in. pounds	f_s=6,100 lbs. per sq. in.
r=24 inches.	I.H.P. =			
D=18.25 ins ...	5,800.....	M=1,275,000 in. lbs.	T_2=6,400,000 in. pounds.....	f_t^1=7,600 lbs. per sq. in.
d=11 inches...	L_1=48 ins.			
R.p.m=110.....	.....	P_1=267,000 pounds ..	T_1=6,400,000 in. pounds.....	f_s=7,800 lbs. per sq. in.
r=24 inches.	I.H.P. =			
D=18.25 ins...	8,000.....	M=1,600,000 in. lbs.	T_2=8,200,000 in. pounds	f_t^1=9,600 lbs. per sq. in.
d=11 inches...	L_1=48 ins.			
R.p.m=120.....	.....	P_1=334,000 pounds ..	T_1=8,010,000 in. pounds.....	f_s=10,100 lbs. per sq. in.
r=24 inches.	I.H.P. =			
D=18.25 ins...	10,700	M=2,004,000 in. lbs.	T_2=10,660,000 in. pounds.....	f_t^1=12,600 lbs. per sq. in.
d=11 inches ..	L_1=48 ins.			
R.p.m=130.....	.....	P_1=404,000 pounds ..	T_1=9,700,000 in. pounds.....	f_s=12,400 lbs. per sq. in.
r=24 inches.	I.H.P. =			
D=18.25 ins...	14,300.....	M=2,424,000 in. lbs.	T_2=13,124,000 in. pounds.....	f_t^1=15,600 lbs. per sq. in.
d=11 ins.	L_1=48 ins.			

* Round numbers used.

Table VII.—Propeller Shafting.

R.p.m.....	W.....	I.T.$=\frac{\text{I.H.P}\times 33{,}000}{\text{P}\times\text{r.p.m.}}$	$M_1=W\times L$. $T_2=M_1+M_2+\sqrt{(M_1+M_2)^2+T_1^2}$ $M_2=W\times L$.	$f_s=\frac{5.1\times D\times T_2}{D^4-d^4}$; $f_t^1=\frac{5}{4}f_s+f_d$.
S.....	P.....	D.....	†$T_1=\frac{\text{I.H.P.}\times 88{,}200}{\text{R.p.m.}}$.....	$f_c=\frac{\text{I.T.}}{\text{net shaft section}}$.
I.H.P.*	L.....	d		
R.p.m.=100 ...	W=31,500..	I.T.=100,000 lbs.....	$M_1+M_2=1{,}700{,}000$ inch lbs.....	f_s=6,950 lbs. per sq. in.
S=17.8..... ..	p=19.75′..	=.....	$T_1=5{,}100{,}000$ inch lbs.....	f_c=630 lbs. per sq. in.
I.H.P.=5,800 .	L=27″.....	D=18 inches.....	$T_2=7{,}050{,}000$ inch lbs.	
		d=10½ inches.....	.....	f_t^1=9,300 lbs. per sq. in.
R.p.m=110.....	.....	I.T.=120,000 lbs.....	$M_1+M_2=1{,}700{,}000$ inch lbs.....	f_s=8,270 lbs. per sq. in.
S=19.4	Same.....	D=18 inches	$T_1=6{,}400{,}000$ inch lbs.....	f_c=800 lbs. per sq. in.
I.H.P=8,000...	.....	d=10½ inches.....	$T_2=8{,}380{,}000$	f_t^1=11,150 lbs. per sq. in.
R.p.m.=120 ...	....	I.T.=149,000 lbs.....	$M_1+M_2=1{,}700{,}000$ inch lbs.....	f_s=9,720 lbs. per sq. in.
S=20.7..	Same.....	D=18 inches.....	$T_1=8{,}010{,}000$ inch lbs.....	f_c=930 lbs. per sq. in.
I.H.P.=10,700	.....	d=10½ inches.....	$T_2=2{,}850{,}000$ inch lbs.....	f_t^1=13,250 lbs. per sq. in.
R.p.m.=130 ...	.....	I.T.=185,000 lbs.....	$M_1M_2=1{,}700{,}000$ inch lbs.....	f_s=11,400 lbs. per sq. in.
S=21.6.....	Same.....	D=18 inches	$T_1=9{,}700{,}000$ inch lbs.....	f_c=1,200 lbs. per sq. in.
I.H.P.=14,300	.....	d=10½.....	$T_2=11{,}550{,}000$ inch lbs.....	f_t^1=15,450 lbs. per sq. in.

* Each shaft.
† Four-crank triple-expansion engines.
Round numbers used in results.

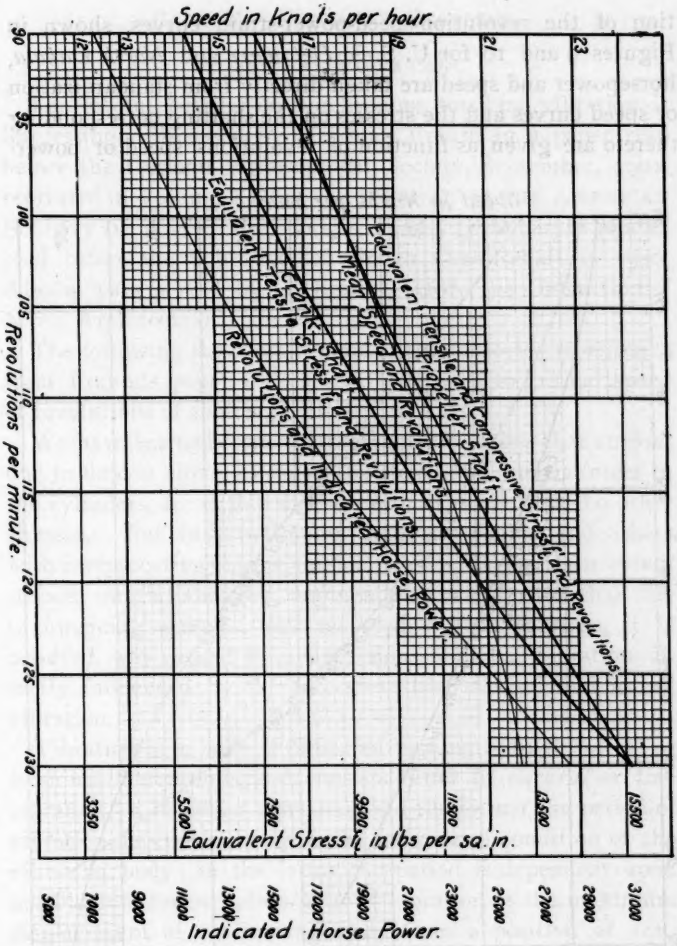


FIG. 9.

There are given in Table VI and Table VII the usual formulae for the obtainance of the equivalent maximum twisting moment and stress per square inch of section of material for both crank and propeller shafts. In the construc-

tion of the revolution-speed-power-strain curves, shown in Figures 9 and 10 for U. S. S. *Delaware* and *North Dakota*, horsepower and speed are taken directly from standardization or speed curves and the stresses on the shafting corresponding thereto are given as function of revolutions, speed or power·

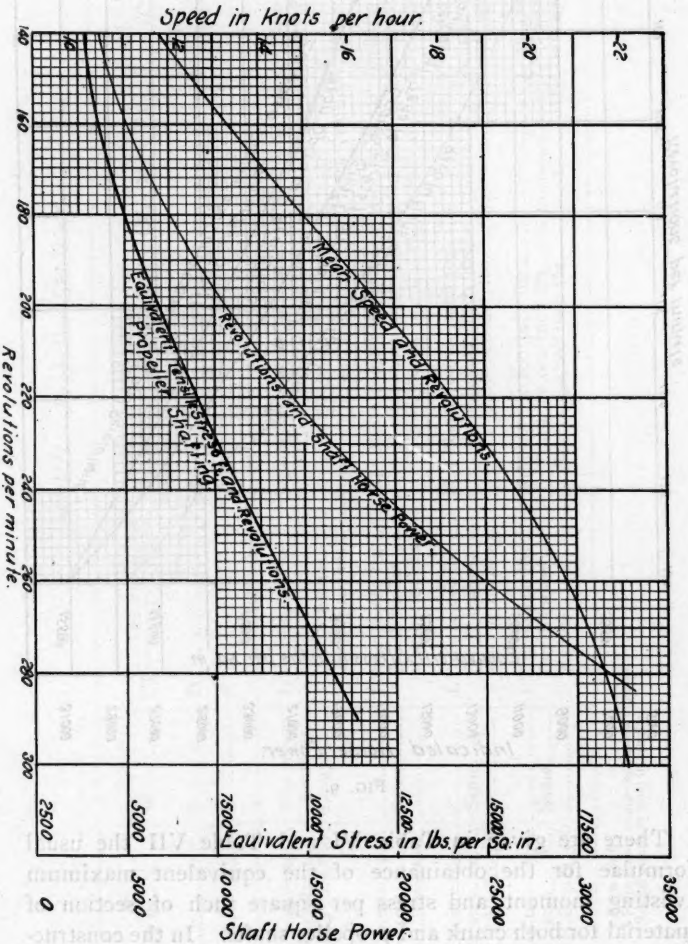


FIG. 10.

PART II.—UNKNOWN STRESSES.

TORSIONAL VIBRATION.

The subject bearing on synchronous torsional vibration is interestingly discussed by Herrman Frahm in a paper read before the German Philosophical Society, September, 1901, reprinted in Volume XIV of the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, and by G. Bauêr, in a paper read before the Schiffbautechnischen Gesellschaft in 1900. Also in papers read by L. Gümbel before the Institution of Naval Architects in 1902 and 1912.

The following is a short resumé of the subject with extracts from Frahm's paper with special reference to critical speed of revolutions of shafting.

We have learned from the previous discussion that stresses due to torsion alone, as caused by steam and inertia forces in the cylinders, are within safe allowances, were there no other stresses. But in experiments made by Frahm and others with reciprocating-engine torsion meters, to ascertain *actual* stresses on the shafting, augmented "twist," over that due to foregoing stresses, was recorded. This increase, it is believed, was caused by synchronous torsional vibration directly influenced by the forces creating natural and forced vibration.

Vibration of a body is indicated by longitudinal, lateral or torsional fluctuations, and consists either in *natural* or free vibration, or in *forced* vibration. In the former the period of vibration depends only upon the nature and condition of the vibrating body; in the latter the period is dependent upon outside influences. *Amplitude* of vibration is the maximum displacement of a vibrating body from a position of rest. *Period* of vibration is the shortest time between instants at which the displacement and velocity of the vibrating body are the same both in amount and direction. This should occur at beginning and end of each revolution, see Figure 11. Within each period of forced vibration of a multiple-expansion marine engine are several individual periods of vibration, each

of which may be termed "period of fluctuation," as seen in the curve of combined twisting moments, or as marked in Figure 11.

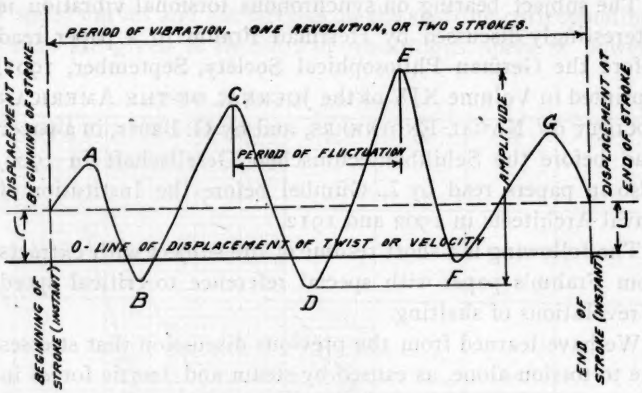


FIG. 11.

Points A, B, C, D, E, F and G are points of maximum displacement during particular instants of the stroke, and their number determine the number of fluctuations which occur during one revolution. Number of fluctuations during each stroke are four in sketch shown.

Torsional vibration in reciprocating marine-engine shafting is indicated on torsion-meter records by a to-and-fro oscillating motion measured from a line of zero displacement. Such vibration is caused by forces created in the cylinders due to steam pressure, inertia of moving parts and by propeller resistance. It may be confined wholly to the shafting of the engine, and as such will create disturbances in the form of severe stresses in the material of the shafting and, generally, in lowering the efficiency. However, if the torsional ship vibration synchronizes with the torsional shaft vibration an aggravated form of vibration, both in ship and engine, may ensue. The turning moment in a reciprocating engine during a revolution is not constant, but varies with different positions of the crank. Thus, for instance, the curves of combined twisting moments in three-cylinder and four-cylinder engines, with cranks, respectively, at 120 degrees and 90 degrees, show

three and four points, respectively, during each revolution at which the torque is greater than the mean torque, and, conversely, three and four points where the torque is less than the mean torque. The foregoing oscillations are principally due to forced vibration. In addition to the forces which bring about forced vibration, free or natural vibration is brought about by the acceleration of the moving masses of engine and propeller. These forces vary and are largely influenced by the elasticity of the shafting, by the damping effect as a result of frictional resistance in shafting, and by the various resistances of the propeller.

To illustrate synchronous vibration one may imagine an ordinary spiral spring firmly secured to a support, which also is capable of movement. At the end of the spring is attached a weight causing vibration of the spring. By the application of an outer force, such as to set in motion the support, the amplitude of motion of the weight may become enormously magnified. This occurs as the frequencies come together, or when the periods of the two vibrations approach synchronism.

Perry shows in his "Calculus for Engineers" that when the forced frequency is a small fraction of the natural frequency the forced vibration of the weight is nearly identical with the motion of point of support. When the forced vibration frequency is increased the motion of the weight is magnified, and when the forced frequency is nearly equal to the natural the amplitude of the motion of the weight is enormously increased. He exemplifies this by the following statement: "When the forced and natural frequencies are nearly equal, we have the state of things which give rise to *resonance* in acoustic instruments; which causes us to fear for suspension bridges or rolling ships." The effect of synchronous torsional vibration in marine-engine shafting, where such occurs, may be partly inferred from the foregoing.

Torsional vibration as measured by Frahm on S. S. *Radamus* increased the ratio of maximum to mean twisting moments in the shafting from 1.3 to nearly 3.3. Synchronous torsional vibration occurs in shafting when the number of the

Table VIII.—Weights of Engine Parts and Propellers.

Synopsis.	U. S. S. *Connecticut.*				U. S. S. *Delaware.*				U. S. S. *Pennsylvania.*			
	H.P.	I.P.	F.L.P.	A.L.P.	H.P.	I.P.	F.L.P.	A.L.P.	H.P.	I.P.	F.L.P.	A.L.P.
Pistons, piston rods and cross-heads	4,000	4,300	4,525	4,370	6,462	7,531	7,825	7,825	8,500	10,500	10,750	10,750
Connecting rods	4,875	4,700	4,550	4,540	7,575	7,575	7,400	7,400	10,000	10,000	10,000	10,000
Total each cylinder	8,875	9,000	9,075	8,910	14,037	15,106	15,225	15,225	18,500	18,500	20,750	20,750
Total all cylinders	35,860 lbs.				59,600 lbs.				78,500 lbs.			
Total propeller	30,100 lbs.				30,500 lbs.				44,800 lbs.			
Length in feet of transformed shaft	104.28				111.08				144.8			
Diameter in inches of transformed shaft	15.5 outside. 9.5 inside.				17.25 outside. 11.00 inside.				20.5 outside. 13.75 inside.			

period of fluctuations in the combined crank-effort curve equals or approaches the order of natural period of vibration of the shaft as caused by the propeller and engine moving parts.

The natural period of vibration is obtained approximately by the following formula, cited in Frahm's paper. The revolutions at which the natural period of vibration synchronizes with the forced vibration are obtained by dividing the former with the number of fluctuations made per revolution. The above revolutions are termed "critical" speed of engine.

We have:

$$N_e = \frac{30}{\pi \times R}\sqrt{\frac{G \times I_p (M_1 + M_2)}{L_0 \times M_1 \times M_2}};$$

where

N_e = Natural period of vibration, or individual number of vibrations per minute;

R = Crank radius, in millimeters;

G = Modulus of elasticity of shaft = 850,000 kilograms per square centimeter;

I_p = Polar moment of inertia;

M_1 = Mass of reciprocating parts referred to crank radius;

M_2 = Mass of propeller referred to crank radius;

L_0 = Length in millimeters of shaft of uniform diameter having same resultant elasticity as original shaft.

The foregoing applied to U. S. S. *Connecticut*, *Delaware* and *Pennsylvania* (latter originally designed for reciprocating engines but later changed to turbines) is given in the following.

The method used in the transformation of the shafting is given in Part I. In table VIII are given weights of reciprocating parts and propellers. The values after insertion of actual figures will be as follows:

U. S. S. "CONNECTICUT."

$$N_e = \frac{30}{\pi \times 24}\sqrt{\frac{850{,}000 \times 4{,}840 \times 2.54 \times 50.25}{1{,}251.4 \times 27.3 \times 22.95}} = 324.$$

Revolutions corresponding to critical speed from

$$\text{R.p.m.} = \frac{324}{4} = 81;$$

Speed in knots corresponding = 12.75.

U. S. S. "DELAWARE."

$$N_e = \frac{30}{\pi \times 24}\sqrt{\frac{850{,}000 \times 7{,}272 \times 2.54 \times 79.1}{1{,}332.96 \times 45.2 \times 23.9}} = 346.$$

Revolutions corresponding to critical speed from

$$\text{R.p.m.} = \frac{346}{4} = 86.5;$$

Speed in knots corresponding 15.5.

U. S. S. "PENNSYLVANIA."

$$N_e = \frac{30}{\pi \times 24}\sqrt{\frac{850{,}000 \times 13{,}818 \times 2.54 \times 93.5}{1{,}737 \times 59.5 \times 34.0}} = 315.4$$

Revolutions corresponding to critical speed from

$$\text{R.p.m.} = \frac{315.4}{4} = 78.75;$$

Speed in knots corresponding = 15.35.

CONCLUSIONS.

Frahm's experiments disclosed that maximum twisting moments, in cases where actual twist of shafting had been ascertained, were for 3-cylinder engines 3.3 times the mean as compared with 1.3 times obtained by the usual method of figuring.

The critical number of revolutions of the 4th order of many of the engines of naval vessels often, unfortunately, constitutes also the cruising speed of the ship. Although the power at this speed is greatly reduced the stress on the shafting due to the equivalent combined twisting moment, observing the above "actual" ratio of 3.3÷1 becomes approximately equal to shafting stresses as large as when engine is developing full

power. These stresses fluctuate between zero and the maximum value in one direction and zero and a maximum value in the opposite direction, the twisting action on the shafting being thus reversed several times during each stroke, the number depending upon type of engine. An imaginary diagram of this is shown in Figure 6, indicated by dot and dash lines. As may be plainly inferred from this diagram the twisting on the shafting produces continuously recurring to-and-fro stresses.

In his experiments (see "Engineering" of June 9, 1871) on rotating steel bars subjected to bending, thus to alternating compressive and tensile stresses, Wöhler found that with a fiber stress of 17,120 pounds per square inch in each direction breakage occurred at a total number of 132,250,000 revolutions. When the stress was increased to about twice the foregoing amount breakage occurred at 4,035,400 revolutions. Again for a stress of 19,260 pounds per square inch the revolutions corresponding to breakage were 19,186,791. Where the bars were subjected to intermittent cross-bending or transverse stresses, as in crank shafts and propeller shafts, the breakage of the bars occurred at a much reduced number of revolutions.

The first accident to one of the crankshafts of U. S. S. *Connecticut* occurred after having made approximately 34,150,000 revolutions with an average stress of (probably) about 14,000 pounds per square inch.

The existence of a considerable increase of stress in shafting of reciprocating-engine ships, due to synchronous torsional vibration at normal or cruising speed of naval vessels, and to overload or other conditions, such as sudden reversal, striking of floating bodies, corrosion, dis-alignment, etc., renders the position reasonable in assuming that shafting, with a designed shear stress of 10,000 pounds per square inch of section (equivalent to probably between 14,000 and 15,000 pounds tensile stress under actual working conditions), becomes severely overstrained. This design stress, therefore, may be lowered in the interest of greater safety, even at sacrifice of greater weight caused by increased dimensions. Designed shear

stress in line and propeller shafting for marine steam turbine installations seldom exceeds 6,500 pounds per square inch of section of steel of 80,000 pounds tensile strength when working nearly at a uniform torque. This shafting, therefore, in comparison with reciprocating engines is working under far more favorable conditions, with the result that accidents in the form of breakage are of rather rare occurrence. Maximum stress in shafting, incident to torque during different working conditions, is difficult to determine by calculation, but may be derived at fairly accurately by tests using torsion meters.

Reasonably satisfactory torsion meters exist for measuring torque on turbine shafting, as meters for this purpose may be made simply enough. The twist on such shafting being only in one direction, corresponding to going ahead or back, it is only necessary to enable measurement of maximum twist, or the torsional displacement of the shaft for a fraction of a revolution. In reciprocating engines, on the other hand, the forces acting create a continuous to-and-fro motion, or what may be termed "twisting and untwisting" of the shaft, the magnitude of which varies continuously during each revolution and between same. It becomes necessary, therefore, to have a meter capable of producing a record for at least one whole revolution, but preferably for an indefinite number of revolutions. Such meters have been made of a combined electro-mechanical type with some degree of success, but, owing to the necessity for considerable skill on the part of operators and errors in interpreting records, such meters have not had extensive application. A purely mechanical torsion meter with direct shaft connections giving a continuous record of torque for a number of revolutions would be of great value in obtaining reliable data in connection with the rather uncertain and difficult subject relating to calculating *stresses in marine-engine shafting*.

U. S. S. *CUMMINGS.*

TRIAL PERFORMANCE.

By Henderson B. Gregory, Associate.

(Note.—The following trial data is a supplement to the Description and Trial Performance of the U. S. S. *Cassin* and *Cummings,* appearing in Volume XXV, August, 1913, number, page 339, of the Journal, to which reference is made for a complete description of the vessels, machinery, etc.)

The trials of the *Cummings* were conducted August 26 to 28, 1913, inclusive, just two months following those of the *Cassin,* her sister ship. The weather conditions were generally good for all the trials.

The standardization trial was run on the measured-mile course, at Rockland, Maine. Twenty-six runs were made, at various speeds, over the measured mile, the data from which are given in Table IV. Unfortunately, at the beginning of the fourth run a slight accident occurred to the torsionmeter on the starboard shaft, rendering it impossible to obtain complete data for the construction of a S.H.P. curve. The official curve was, therefore, constructed by combining the S.H.P. data obtained for the port shaft on the standardization trial with that of the starboard shaft obtained on the full-power, 24, 15½ and 12-knot trials. The curves shown in Figure 5 are plotted from the official curves.

It was found, from the official speed and revolution curve, to require the following mean revolutions per minute of the propellers to attain the speeds stipulated for the other trials:

Number of Run	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Time on Course: Mins.	5	5	5	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1
Secs.	1.9	2.1	2.8	57	53.6	50.7	27.5	22.9	24.7	48.1	52.2	48.6	30	28.2	30.5	15.3	17.3	15.6	5.9	3.8	4.7	53.3	54.8	53.6	54.5	53.85
Revolutions, to go 1 Knot:																										
Starbd. Shaft	922.8	931.0	914.3	940.4	932.8	934.2	1038.6	1028.7	1035.0	1024.6	1037.5	1023.4	1072.5	1032.8	1071.3	1099.5	1109.7	1098.0	1151.3	1145.7	1144.6	1193.1	1188.6	1185.6	1192.5	1196.8
Port Shaft	1042.6	1044.4	1041.6	1058.8	1053.1	1044.7	1003.6	992.5	1008.1	1000.7	1010.5	997.7	1050.5	1039.0	1051.5	1079.3	1092.7	1080.6	1133.0	1127.6	1128.8	1166.2	1270.5	1271.6	1273.5	1277.0
Average	982.7	987.7	978.0	999.6	993.0	989.5	1016.7	1008.1	1021.6	1012.6	1023.9	1010.6	1061.5	1045.8	1061.4	1089.4	1101.2	1089.3	1142.2	1136.7	1136.7	1229.7	1229.6	1233.5	1233.0	1236.9
R.P.M.:																										
Starbd. Shaft	183.31	184.96	181.16	264.15	259.54	243.85	297.80	308.78	303.36	305.46	301.57	314.20	428.98	428.88	427.06	487.0	498.85	486.11	548.48	555.69	550.95	631.27	621.64	631.21	623.27	629.89
Port Shaft	207.18	207.58	206.39	278.85	270.53	271.78	289.87	293.49	295.34	301.77	332.23	355.04	420.29	420.84	419.11	478.71	477.40	478.38	568.29	576.03	572.22	664.92	646.47	671.19	665.60	672.11
Average	195.27	196.28	193.78	259.00	254.98	257.81	293.84	298.11	299.31	303.61	316.90	334.62	424.59	424.86	423.08	482.9	488.13	482.25	558.34	565.86	561.59	650.57	643.06	651.20	644.44	651.00
Speed in Knots	11.924	11.917	11.889	15.584	15.411	15.605	13.949	13.745	13.587	14.116	20.906	21.352	24.000	24.292	23.920	24.606	24.220	24.549	28.574	29.079	28.869	31.774	31.359	31.690	31.441	31.620
S.H.P.: Starbd. Shaft	161	186	182	Torsionmeter Point Broke on Run No 4																						
Port Shaft	432	478	501	975	963	951	925	946	997	1820	1708	1787	3121	3152	3062	4555	4836	4787	7327	7390	7410	9868	10399	10175	10256	10108
Total	593	664	683																							
Engines in Operation	Recip. Engine, H.P. & L.P. Turbines									H.P. & L.P. Turbines (Steam on H.P. Cruising Belt)												H.P. & L.P. Turbines				

TABLE IV.—STANDARDIZATION TRIAL DATA, U. S. S. "CUMMINGS."

	4-Hour Full Power Trial (b)	4-Hour 24-Knot Trial (c)	4-Hour 15½-Knot Trial (d)	20-Hour 15½-Knot Trial (e)	4-Hour 12-Knot Trial (f)
Date of Trial	Aug. 27, 1913	Aug. 27, 1913	Aug. 28, 1913	Aug. 28 & 29, 1913	Aug. 28, 1913
Speed in Knots	30.574	23.991	15.47		11.946
Slip of Propellers, per cent. of own speed, mean:					
Starboard	22.68	14.81	3.13		-0.25
Port	26.31	11.89	12.74		14.15
Draught, mean on trial, feet and inches	9-3⅜	9-4½	9-4½		9-5⅛
Displacement, corresponding, tons	10143	1024	1022.8		1030
Engines in operation	H.P. & L.P. Turbine	H.P. & L.P. Turbine	*		*
Number of boilers used	4	4	1		1
Oil burners used (12 per boiler)	48	18½	6	No data taken	4
Heating surface used, square feet	21500	21500	5375		5375
Pressures (average):					
Main steam, at boilers, pounds gauge	257.5	204.9	223.5		180.6
Steam chest, pounds gauge	251.1 (H.P.M. Belt)	193.2 (H.P.C. Belt)	205.9 (Recip. Eng.)		115.6 (Recip. Eng.)
Vacuum in condenser, inches of mercury	28.48	29.1	27.8		27.8
Main feed, pounds gauge	345	343.8	337.5		237.5
Air pressure in fire rooms, inches of water	6.25	4.2	3.43		2.05
Revolutions per minute of propellers (average):					
Starboard	602.01	428.04	242.71		181.12
Port	630.56	413.86	269.44		211.5
Mean	615.19	420.95	256.07		196.31
Collective S.H.P., from curve	16335	6277	1342		622

* Reciprocating Engine, H.P. and L.P. Turbines.

TABLE V.—TRIAL DATA, U. S. S. "CUMMINGS."

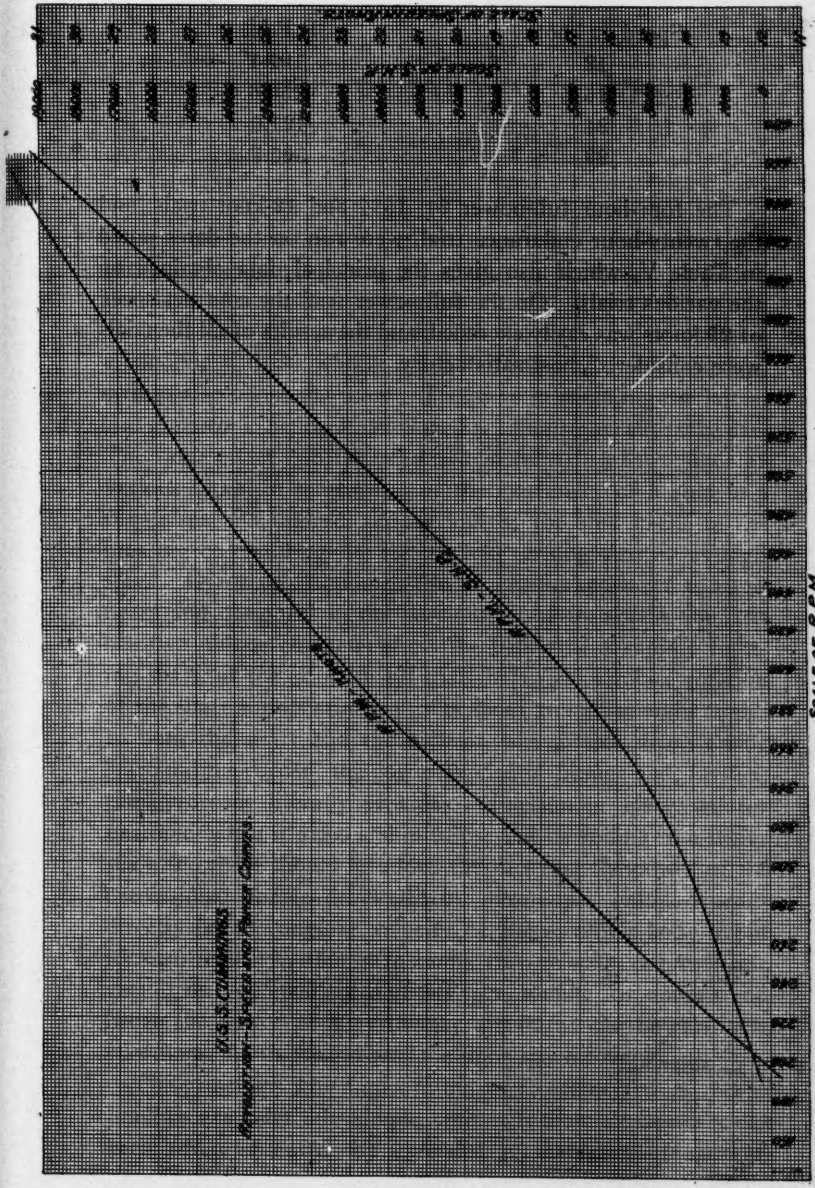


FIG. 5.

Speed, in knots.	R.P.M.
12	197.1
15½	256.6
24	421.0
29	565.5

The four-hour full-power 24, 15½ and 12-knot trials, and the twenty-hour endurance trial, were run on the dates noted in Table V, which also gives the principal data obtained on the various trials. On the full-power trial the contract speed of 29 knots was easily exceeded, and the results of all the trials were considered most satisfactory.

SOME NOTES ON GYROSCOPIC ACTION.

By Wm. L. Cathcart, Member.

In certain conditions the effect of gyroscopic action on engineering constructions may be marked. It occurs whenever the shaft of a rapidly revolving body is given partial rotation about another axis at an angle with the shaft. For example, a car axle with its wheels, while turning in its own bearings, swings also about the center of a curve in rounding the latter, and gyroscopic action is developed tending to overturn the car. The same effect is often produced in centrifugal machines of various types, in some parts of the machinery of a ship in a rough sea and, indeed, on the hull of the ship itself, in depressing or elevating the stern when turning sharply at high speed. Gyroscopic action is also of much importance to engineers and designers in the possibilities of its application. It has two unique characteristics: the tilting of a rapidly rotating shaft, or the effort to tilt that shaft, will produce rotation of the shaft and its attached parts about an axis at right angles to both the shaft and the axis of tilting, thus transferring "around the corner" the power applied in tilting; and, further, the gyroscope literally provides a fulcrum in space, as, for example, when it grips a ship to prevent its rolling in a heavy sea. To these should be added the fact that the power of the precessional couple developed by gyroscopic action depends directly on the angular velocity of the spinning body about its own axis. Within safe limits this velocity can be made very great—15,000 revolutions per minute or more—and hence the power of a gyroscopic apparatus can be relatively enormous for its weight and the floor space covered.

The principles which govern most gyroscopic actions met in practice are relatively simple, although their explanation has been often obscured by extended mathematical treatment.

This has been due largely to the assumption that, in any such action, we should consider unsteady motion and nutation, which is the minute wobbling or vibration of the shaft of the spinning body. In practice this assumption is in most cases unwarranted, since it holds only with suddenly-applied loads when the moment of inertia of the spinning mass about the axis of precession is relatively large as compared with the angular momentum of the mass about its own axle.

Although, if we disregard nutation, the principles governing gyroscopic action and its effects are relatively simple, the application of these principles is somewhat confusing when the subject is for the first time investigated in detail. The notes on which this article is based were gathered during the writer's study of the application of the gyroscope as a compass and in preventing the rolling of ships. While necessarily somewhat elementary, they are presented here in the view that possibly they may be of service to other engineers in similar case. For more detailed information the reader is referred to Worthington's "Dynamics of Rotation," the "Lecture on Spinning Tops" by Professor John Perry, "Spinning Tops," etc., by H. Crabtree, the papers of Mr. Elmer A. Sperry and Lieutenant Gillmor in the "Transactions of the Society of Naval Architects and Marine Engineers," and that of Mr. Sperry in the "Journal of the Franklin Institute."

THE GYROSCOPE.

Fig. 1 shows the well-known form of the gyroscope as used for demonstrating purposes. The disc *A* is secured to the axle *XX*, and, through gimbal suspension, is mounted with "three degrees of freedom," that is, it and its axle can rotate about the axis *XX;* the disc, its axle and the ring *B* can revolve about the axis *YY*, passing through the extremities of the forked frame *C;* and the disc, ring and fork, owing to the socket bearing at *D*, can rotate together about the vertical axis *ZZ* passing through the center of the stand *E*. Normally each of the three axes is perpendicular to the other two.

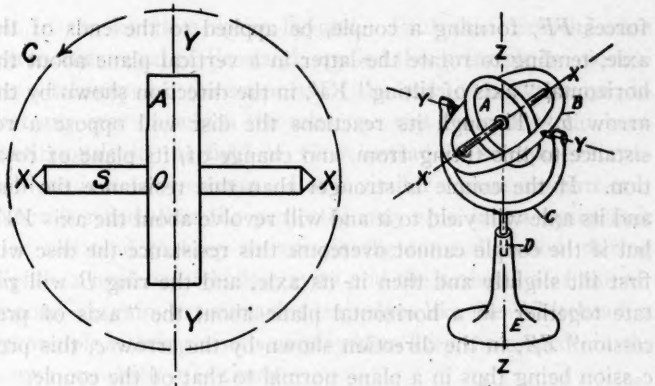


FIG. 1.

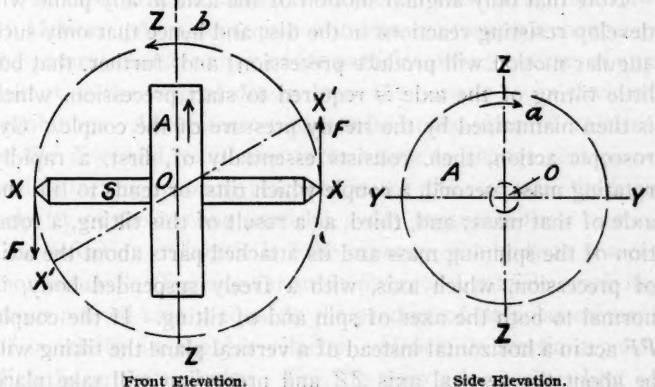


FIG. 2.

The method of suspension is sometimes changed so that the axis *XX* is vertical and the disc horizontal, the mounting being the same in other respects. All bearings, while accurately fitted, are made as frictionless as possible.

PRECESSION.

For clearness, the disc and its axle are shown without framing in Fig. 2, all other conditions remaining the same. With the axle horizontal and the disc revolving rapidly in the direction shown by the arrow *a*, let the two equal and opposite

forces *FF*, forming a couple, be applied to the ends of the axle, tending to rotate the latter in a vertical plane about the horizontal "axis of tilting" *YY*, in the direction shown by the arrow *b*. Through its reactions the disc will oppose a resistance to this tilting from, and change of, its plane of rotation. If the couple is stronger than this resistance the disc and its axle will yield to it and will revolve about the axis *YY;* but if the couple cannot overcome this resistance the disc will first tilt slightly and then it, its axle, and the ring *B* will rotate together in a horizontal plane about the "axis of precession" *ZZ*, in the direction shown by the arrow *c*, this precession being thus in a plane normal to that of the couple.

Note that only angular motion of the axle in any plane will develop resisting reactions in the disc and hence that only such angular motion will produce precession; and, further, that but little tilting of the axle is required to start precession, which is then maintained by the steady pressure of the couple. Gyroscopic action, then, consists essentially of, first, a rapidly rotating mass; second, a couple which tilts, or tends to tilt, the axle of that mass; and, third, as a result of this tilting, a rotation of the spinning mass and its attached parts about the axis of precession, which axis, with a freely suspended body, is normal to both the axes of spin and of tilting. If the couple *FF* act in a horizontal instead of a vertical plane the tilting will be about the vertical axis *ZZ* and precession will take place about the horizontal axis *YY*. In other respects the operation will be identical with that shown in Fig. 2.

INERTIA, THE FUNDAMENTAL CAUSE OF PRECESSION.

In 1851–2 Foucault, the French physicist, as a result of his celebrated analysis of gyroscopic phenomena, laid down the fundamental law that the inertia of a rapidly rotating disc, which is so suspended as to be free to move in all directions, is "relative to space," that is, if unacted upon by external forces the disc will always keep in the same plane of rotation and its axle will always point in the same direction, not on the earth

but in the limitless space beyond. Professor Smyth, once astronomer-royal of Scotland, applied this principle by mounting a telescope on the supports of the ends of a gyroscope, so that any star on which the telescope was trained would keep continuously in the field of view instead of sweeping across the lens in a few seconds. For a similar reason modern ordnance is rifled, that the projectile may spin like a gyroscopic disc and tend to keep its axis in the same direction during flight—a tendency which gravity and the resistance of the air oppose. Again, in submarine torpedoes like the Whitehead, a gyroscopic steering disc is employed to keep the torpedo in the course on which it is aimed.

The disc, in its rotation, is subject to Newton's First Law of Motion. As a consequence inertia opposes any change in the natural course of any of its particles, which course, at any instant, is the tangent drawn from the particle to its circle of revolution. All of these tangents lie in the plane of rotation of the disc, and hence any force acting to change that plane will be met by opposing reactions in the disc. Again, the high velocity of the moving particles vastly augments their inertia. One definition of inertia is "the capacity of a body to possess momentum." The angular momentum of a particle revolving about a fixed axis is equal to the product of its polar moment of inertia by its angular velocity. Hence, its inertia depends directly on that velocity. For this reason a circular sheet of thin silk, if revolved at very high speed as a disc about its center, will become as rigid as steel. In the Sperry apparatus for stabilizing ships one pound of metal in the rotating disc does the work of 150 pounds or more applied in any ordinary engineering way, although the speed of the disc is relatively low.

It is this practically limitless increase of inertia which makes the gyroscope capable of thus establishing a fulcrum in space.

In speaking of the "resistance" of the rotating disc to a change in its plane of rotation, an ordinary and convenient, although strictly speaking incorrect, expression has been used.

The resistance thus met is really indirect and the resultant of the reactions, due primarily to inertia, which the rotating particles oppose to angular movement when an attempt is made to tilt the disc. General Barnard, for many years President of Columbia University, said*: "The popular idea that a rotating body offers any *direct* resistance to a change of its plane is unfounded. It requires as little exertion of force (in the direction of motion) to move it from one plane to another as if no rotation existed; and, as a corollary, as little expenditure of work. But deflecting forces are developed, by *angular* motion given to the axis and normal to its direction, which are very sensible and are mistaken for *direct* resistances. * * * What, then, is the resistance to a change in plane, so often alluded to and described? A misnomer entirely."

With regard to the maintenance of the original plane of rotation in space a modifying condition may be noted, although it has no bearing on ordinary gyroscopic apparatus. As the earth, on which the rotating disc is located, is a revolving body; it acts on the disc with a tendency to align the disc-axis with its own. Hence, a wholly free disc under this influence will gradually swing around from any given position until its axis points geographically north and south. This is the principle which has been applied with full success in the Sperry Gyro-Compass, with, on a moving vessel, a slight correction automatically made for speed, course and latitude. The directive action of the earth is, however, extremely feeble and has no appreciable effect on ordinary gyroscopic construction. To utilize it in the gyro-compass, the disc is suspended by torsionless strands of wire and an auxiliary, motor-driven "follow-up" mechanism is employed to supplement the earth's directive power, so that the latter acts only as an indicator of the required motion of the disc, the follow-up gear doing the actual work of driving it. The principle of the earth's directive action is, however, general, applying in greater or less degree to every rotating body on its surface, so that the shaft

*Anaylsis of Rotary Motion as Applied to the Gyroscope, p. 40

of every flywheel, of every dynamo and motor, is striving feebly and vainly to swing around to the geographic north. This tendency—the "effort to precess"—is resisted by the bearings, and hence no precessional action takes place.

THE GYROSTAT.

In the gyrostat precessional gyration occurs; but the axes of spin, tilting, and precession do not meet in a common point, the center of the disc, as in the gyroscope proper, since the spinning mass is free to revolve on a horizontal plane. The bicycle when the driving wheel is turned, the top spinning with an inclined axis, and a child's hoop when moving in a circle are all examples of gyrostatic action.

The top especially has been the subject of exhaustive study since the early days of the investigation of the phenomena of spinning bodies. In fact, the precession of the earth is like that of a gigantic spinning top. When the axis of the top is inclined, as shown in Fig. 3, it has precessional gyration about the vertical axis PP passing through the center of gravity G. The axis of spin SS is tilted by the weight W acting at the center of gravity and the equal and opposite reaction W at the point of contact with the supporting plane. The arm of this couple is $a = r \sin \theta$, in which θ is the inclination of SS to the vertical. The magnitude of the couple is hence $Wr \sin \theta$. It will be seen that we have, as before, axes of spin and tilting, and precession about a third axis. The spin and precession are in the same direction. These expressions are based on the assumption of steady motion of the top. Its motion is, however, not absolutely steady, since the axis SS has a minute nutation which acts to corrugate the circular path, as shown in the upper part of the figure. Centrifugal forces also modify somewhat the rate of precession, the character—acceleration or retardation—and amount of this modification depending on the form of the top.

The child's hoop gives another familiar example of precessional gyration. While vertical it runs in a straight line with

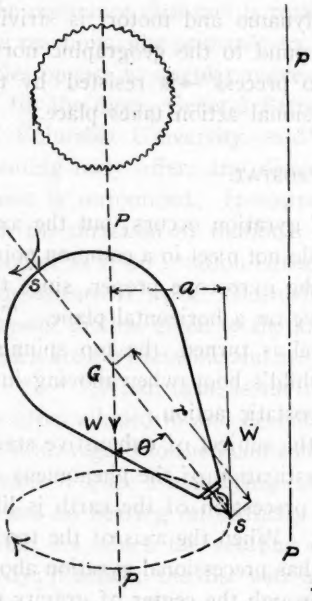


FIG. 3.

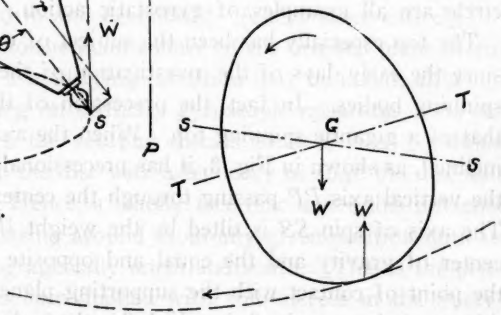


FIG. 4.

the axis of spin *SS* horizontal; when, as shown in Fig. 4, it is tilted about an axis *TT* in its plane and passing through its center of gravity *G*, it precesses about a third and vertical axis *PP* passing through the center of its circular track. As with the top, the continuous tilting couple is the weight acting at the center of gravity and the equal and opposite reaction at the ground. The initial tilting force is the pressure of the guiding stick.

GYROSCOPIC REACTIONS.

As has been stated, the pressure of the tilting couple on the axis of spin is opposed by reactions due to the inertia of the particles of the tilted disc. The resultants of these reactions

form a couple tending to produce precession. The precession couple thus generated balances the tilting couple through its reacting effect on the axle of spin. Again, by the principles of the Conservation of Momentum, the angular velocity of precession is evidently equal to the angular velocity of tilting about any axis which is perpendicular to the axis of spin.

If unsteady motion and nutation be considered, the derivation of formulae connecting gyroscopic torque and precession is a complex mathematical process. A much simpler way and one which suffices for most of the problems which engineers meet in practice, is that given by Professor Worthington in "The Dynamics of Rotation," in which only steady motion is assumed and the derivation of the formulae is founded broadly on the Conservation of Angular Momentum. The discussion which follows is based largely on the methods of Professor Worthington.

The forces which start precession are shown in Fig. 5. The

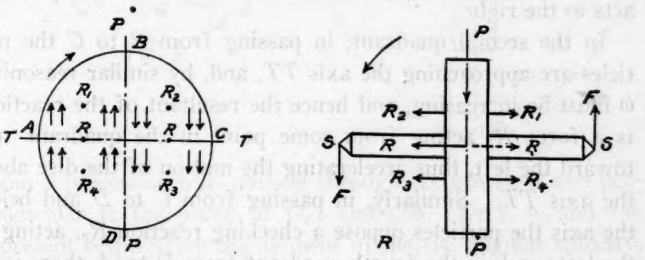


FIG. 5.

axle of spin revolves toward the front and the tilting couple, applied in a vertical plane, tends to rotate it in a non-clockwise direction, when viewed from the front. There are thus two rotations given each particle of the disc, one about the spinning axis *SS*, the other about the tilting axis *TT*. By the principles of Conservation, the angular momentum is constant in all four quadrants of the disc's rotation. This momentum is equal to $I\omega$, in which I is the moment of inertia of the disc

and ω is its angular velocity about the given axis, in this case the axis of tilting TT.

In the first quadrant of the tilted disc's rotation, the particles are receding from the axis TT, in passing from A to B. Hence, with regard to that axis, I is increasing, and, as $I\omega$ is constant, ω must be decreasing, that is, the resultant of all the reactions of the particles in this quadrant is a force R_1 which must act toward the right from some point in the quadrant in order to check the rotation of the disc about the axis TT. This follows from the fact that any force, acting on any quadrant of the disc, to level the axle SS will retard rotation about the axis TT, and that any force which tends to increase the tilting will accelerate the rotation about TT. Further, the direction of such a retarding force acting *above* the axis TT must be to the right, and that of a retarding force *below* this axis, to the left; accelerating forces must act in directions the reverse of these. Hence, R_1, being a retarding force above the axis, acts to the right.

In the second quadrant, in passing from B to C the particles are approaching the axis TT, and, by similar reasoning, ω must be increasing, and hence the resultant of the reactions is a force R_2 acting from some point in the quadrant and toward the left, thus accelerating the motion of the disc about the axis TT. Similarly, in passing from C to D and below the axis the particles oppose a checking reaction R_3, acting to the left; and, in the fourth quadrant from D to A, there is an accelerating reaction R_4, acting to the right.

The resultant of the two equal forces, R_1 and R_4, is a force R acting toward the right in the plane of the axis SS and from a point in the axis TT. The resultant of the two equal forces, R_2 and R_3, is a force R acting toward the left, also in this plane but on the other side of the axis SS. The two forces RR therefore form a couple, acting in the plane of the axis SS and tending to revolve that axle and the disc about the axis of precession PP as shown by the arrow a. If, when precession has once begun in this way, the same method of reasoning be

applied to the quadrants in their rotation about the axis of precession, it will be found that this rotation and that of the disc about the axis of spin generates a couple about the axis TT which opposes and balances the tilting couple FF.

GYROSCOPIC TORQUE AND PRECESSION.

There are a number of ways of deriving the formulae connecting gyroscopic torque and precession. Professor Worthington* gives a clear and simple method, as follows:

In Fig. 6, $OA = OB$ represents the axis of spin revolving

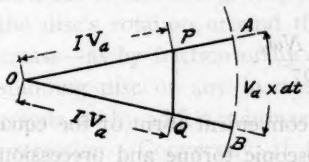
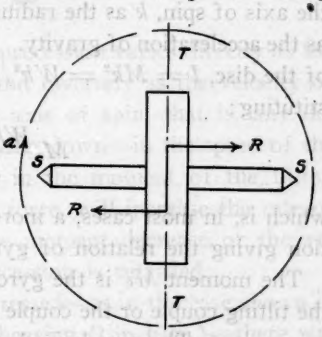


FIG. 6.



Top View.

about a precession axis passing through the center O and perpendicular to the plane of OA and OB. Let I, ω_1, and $I\omega_1$ represent respectively the moment of inertia, angular velocity, and angular momentum of the disc about the axis of spin, and let ω_2 be the angular velocity of the disc and its axle in their rotation about the axis of precession.

On any convenient scale take $OP = OQ = I\omega_1$. Then PQ represents the increment of angular momentum during the time t required for the axis of spin to rotate from OA to OB. If this time be taken as dt, OA and OB nearly coincide, and hence PQ may be considered as perpendicular to OA. Let M_c be the moment of the tilting couple. Then, the angular momentum added during the time dt is $M_c \times dt$. Therefore,

* Dynamics of Rotation, New York, 1897, p. 146.

$$\frac{PQ}{OP} = \frac{M_c \times dt}{I\omega_1}.$$

But, PQ/OP is the sine of the angle POQ, and, since that angle is indefinitely small, is equal to the angle. Again, since velocity $\times$ time = space traversed, $\omega_2 \times dt$ = arc AB = angle AOB = angle POQ. Therefore,

angle $POQ = PQ/OP = \omega_2 dt = M_c dt/I\omega_1$, or $M_c = I\omega_1\,\omega_2$.

Let M_c be taken in pound-feet, the weight W of the rotating mass in pounds, ω_1 and ω_2 in radians per second, N as the number of revolutions per minute of the rotating mass around the axis of spin, k as the radius of gyration of the disc, and g as the acceleration of gravity. Then, if $M = W/g$ be the mass of the disc, $I = Mk^2 = Wk^2/g$. Also, $\omega_1 = 2\pi N/60$. Substituting:

$$M_c \frac{Wk^2\,N\omega_2}{307}.$$

which is, in most cases, a more convenient form of the equation giving the relation of gyroscopic torque and precession.

The moment M_c is the gyroscopic moment—that of either the tilting couple or the couple causing precession or the effort to precess. The angular velocity ω_2 of precession is also, in general, the angular velocity of tilting the disc about any axis perpendicular to the axis of spin. In starting from rest work is done by the tilting couple on the disc, and the latter tilts somewhat before it resists fully and the angular velocity of precession is attained. Hence, strictly speaking, the formulae as above for M_c are limited to the moment required to keep the disc precessing steadily after that action has begun. As the magnitude of the couple causing, or tending to cause, precession varies directly as the weight and speed of the spinning disc, and as the velocity of the latter is limited only by the stresses arising from centrifugal action, the power which can be developed in a relatively small space by gyroscopic action is enormous. In the gyro-stabilizer built for the U. S. Torpedo-boat Destroyer *Worden*, the axis of precession is

horizontal and the force developed by precession acts on the holding-down bolts of the apparatus. During preliminary trials at the Navy Yard, New York, the gyro was bolted to a bedplate weighing 67,000 pounds, and, when precessing, it easily tipped this plate.

ACCELERATION, RETARDATION, AND DIRECTION OF PRECESSION.

The equation for gyroscopic torque and precession may be written:

$$\omega_2 = \frac{M_c}{I\omega_1}.$$

Hence, the angular velocity of precession varies directly as the moment of the tilting couple and inversely as the velocity of the disc's rotation around the axis of spin, that is, any decrease—as by friction or by dying down—in the speed of the spinning disc or any increase in the moment of the tilting couple, as by added impressed force, will increase the rate of precession. Conversely, if the moment decrease or the velocity of spin increase the precession is retarded.

If precession be wholly suppressed—as in the case shown in Fig. 2 by clamping the socket bearing *D* in Fig. 1—there will be no gyroscopic reactions in the disc, and the tilting couple will turn the disc, its axle, and the ring as freely as if the disc were not revolving. This reduction of resistance to tilting exists always in greater or less degree, when precession is impeded, and the resistance disappears wholly when precession is suppressed. As Professor Worthington points out, the turning over of the disc under the action of the tilting couple when precession is impeded is itself but a precessional motion induced by the impeding torque, which, in the case just cited, acts at the socket bearing *D*. In general, with gyrostats like the spinning top, the axis of the spinning body moves toward the vertical, in opposition to gravity, when the velocity of precession increases, and *vice versa*.

When the axis of spin is inclined and not horizontal as in

ships. With his apparatus a considerable movement of the ship was required before the gyro would act, and hence it modified but did not prevent rolling.

Finally, Mr. Sperry has recently applied the gyroscope to the maintenance of the longitudinal and lateral stability of aeroplanes.

U. S. FLEET COLLIERS *PROTEUS* AND *NEREUS*.

DESCRIPTION AND TRIALS.

By Henderson B. Gregory, Associate.

Fleet Colliers Nos. 9 and 10, the *Proteus* and *Nereus*, were authorized by an Act of Congress approved June 24, 1910. The contracts for their construction were awarded to the Newport News Shipbuilding and Dry Dock Company, of Newport News, Virginia, and were signed August 29, 1911, the price being $990,000.00 each, and the time of construction twenty-two months. They were designed for a speed of fourteen knots, when carrying not less than 12,500 tons of cargo and bunker coal, corresponding to a displacement of about 19,000 tons, with the main engines developing about 6,700 I.H.P.

The construction of the vessels was in conformity with the Rules of the American Bureau of Shipping and the Rules of the United States Steamboat Inspection Service, and inspection was carried out during their construction by the Inspector of Machinery for U. S. Navy, at the works of the contractors.

PRINCIPAL HULL DIMENSIONS.

Length over all, feet and inches	521–9
between perpendiculars, feet and inches	500–0
on load water line, feet and inches	502–1⅝
Beam, extreme, feet and inches	62–2½
on load water line, feet and inches	62–2½
moulded, feet and inches	62–0
Mean designed draught, feet and inches	27–6
Displacement at designed draught, tons	19,080
per inch at L. W. L., tons	63.6

Area of immersed midship section at designed draught, square feet	1,684
L. W. L. plane at designed draught, square feet	26,722
Wetted surface at designed draught, square feet	48,900
Coefficient of fineness, block	0.778
midship section	0.988
load water line	0.863

GENERAL DESCRIPTION OF HULL.

The vessels are of steel, twin-screw, single-deck, self-trimming type, with topside ballast tanks and raised forecastle and poop deck.

Navigating Bridges.—There are two bridges located above and at after end of the forecastle deck. The upper bridge is open and fitted with steering gear and searchlight platform, on which is mounted one searchlight. The lower bridge is semi-inclosed with steering platform in center, and chart house and bridge cabin, port and starboard, respectively.

Forecastle Deck.—This deck extends from the bow to frame No. 29, and on it are located the anchor windlass, two small booms for loading stores aboard and minor deck fittings.

Poop Deck.—The poop deck extends from frame No. 136 aft. On this deck is located a spacious deck house containing the officers' quarters, wireless-telegraph room, officers' and crew's galleys, pantries and bakery. There is also a small steam capstan aft of the deck house.

On top of the deck house are carried the boats, swung in davits at the vessel's side, and also a small coaling winch for the after steaming bunkers.

Upper Deck.—The upper deck is continuous from the stem to the stern. It is a weather deck from frames No. 29 to No. 139. Under the forecastle are located the lamp room, paints and oils room, windlass engine, berthing space and crew's water closets. On the weather portion of this deck are the hold hatches, coaling winches and A-frame towers for the coaling gear. The forward and after towers are fitted as masts for lights, signal purposes and wireless outfit. Aft under the poop deck are the executive officer's and chief en-

gineer's offices, crew's and firemen's wash rooms and water closets, crew's and chief petty officer's quarters, hospital and steering-gear room.

Berth Deck.—The berth deck is interrupted between frames No. 34 and No. 162 by the cargo holds and machinery spaces. Forward are a storeroom and spare berthing space, and aft are located the engineer's stores, refrigerating and dynamo machinery, crew's and spare berthing space.

Lower Deck.—Like the berth deck, the lower deck is small in area, extending from the bow to frame No. 34 forward, which space is completely occupied by storerooms, and from frame No. 175 aft, where are located the refrigerating rooms, stores and fresh-water tanks.

Hold.—From forward aft the hold contains the following: Forepeak tank, chain locker, pump room (not equipped), holds for stores, cargo-coal holds, steaming-coal bunkers, boiler and engine rooms and the after-peak tank. Under the boiler room are located the reserve feed tanks. Holds Nos. 1 to 8 are constructed to carry cargo oil, but the piping and pumping equipment for same is left for future installation.

BOATS CARRIED.

The following small boats and life rafts are carried on top of the deck house and in davits at the ship's side:

1 33-foot sailing launch with power;
2 28-foot whale boats;
1 21-foot power dory;
1 20-foot dinghy;
1 14-foot punt;
2 16-foot 8-inch life rafts.

DECK MACHINERY.

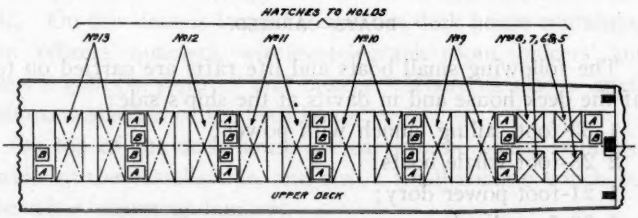
Anchor Windlass.—A Hyde steam anchor windlass is located on the forecastle, with engine below on the upper deck. The engine is of the vertical type with two steam cylinders 16 inches diameter by 12 inches stroke each.

Steering Engine.—The steering engine is located on the upper deck aft of the crew's berthing space. It is the Hyde Steam Windlass Company's horizontal type with two steam cylinders 10 inches diameter by 8 inches stroke each.

Capstan.—Aft of the deck house on the poop deck is a Hyde capstan operated by a horizontal steam engine with two cylinders 8 inches diameter by 8 inches stroke each.

COALING GEAR.

Twenty-four Mead-Morrison coaling winches are located on the weather portion of the upper deck, in five groups of four and two groups of two winches each, as shown in Figure 1. They are arranged, one grab and one swing winch per hatch, except for the four small hatches forward, which are served in pairs by the same two winches. There are ten large hatches to the main holds. Each winch has double steam cylinders, 10 inches diameter by 12 inches stroke each for the grab winches, and 8½ inches diameter by 10 inches stroke each for the swing winches. The gear is operated by one man per winch.



A = Grab or hoisting winches. B = Swing or transverse travel winches.

FIG. 1.—ARRANGEMENT OF COALING WINCHES AND HATCHES U. S. F. C. "PROTEUS" AND "NEREUS."

There is also a small winch on top of the deck house aft for loading bunker coal. It has two steam cylinders 8¼ inches diameter by 10 inches stroke each.

Seven A-frame towers, each about 50 feet high above the upper deck, are erected, one over each group of winches.

These towers form the supports for the booms, stays and running gear used in loading and discharging cargo coal. The after tower is also used for loading bunker coal. There are four steel-girder booms of box section pivoted to each tower, two port and two starboard, except the forward tower, which has but two, one port and one starboard. These booms are suitably guyed and support the cables on which the coal conveyors travel.

The coal is handled by mechanically operated clamshell buckets of the Mead-Morrison type, each of one ton capacity. The contractors guaranteed a discharging capacity of 75 tons per hour per hatch, when discharging from all hatches simultaneously, which guarantee was easily exceeded on the trials conducted.

VENTILATION.

Cowls in number, location and size, as required for an efficient system of natural ventilation, are provided.

HEATING SYSTEM.

All living spaces, offices, bridge houses and quarters are steam heated in accordance with the usual practice.

STEAM FIRE-EXTINGUISHER SYSTEM.

A steam fire-extinguisher system is provided, consisting of 1½-inch independent connections to each hold. Steam is taken off the deck auxiliary steam line with a stop valve at each connection to the main cargo-coal hold. The steam to the eight forward holds, which may be used for oil, is controlled by an eight-valve manifold just aft of their hatches.

FIRE MAIN.

The fire main is supplied by a 5-inch connection from the fire and bilge pump and one of 7 inches from the ballast pump. It is also cross-connected with the sanitary system by a 3½-inch branch aft. The fire main and topside ballast system are

in common. Varying in diameter from 7 to 3½ inches, it extends fore and aft on the upper deck, port and starboard, with hose valves conveniently located on the mains, and branches to the various parts of the vessel requiring hose plugs for fire protection and general purposes. All hose plugs are for 2½-inch standard fire hose.

DRAINAGE, PUMPING AND FLOODING SYSTEMS.

An efficient drainage, pumping and flooding system is provided for the double-bottom tanks, topside ballast tanks, peak tanks and compartments requiring drainage. The tanks are filled and emptied through piping connected through manifolds to pumps in the engine room, except the fore-peak tank, which is emptied by a small 6-inch × 5¾-inch × 6-inch horizontal, duplex pump, located in the pump room forward; and the topside ballast tanks, which drain overboard direct, through valves operated from the weather deck. The above mentioned pump also has a suction connection to the chain-locker bilge well.

The topside ballast tanks on each side of the vessel are filled by pipes run on the upper deck with a branch and valve to each tank. These pipes are also used as the fire main, and have a branch from the starboard main for filling the fore-peak tank.

The usual strainers are fitted in all drainage suction pipes to guard against coal dust, dirt, etc., choking the pipes or entering the manifolds and pumps.

The double-bottom reserve feed tanks have connections only to the fresh-water pumps, and have filling pipes from the ship's side.

SANITARY SALT AND FRESH-WATER SYSTEMS.

The salt-water flushing system is connected to the sanitary and distiller circulating pumps in the engine room. It is also cross-connected with the fire main aft. It supplies salt water

to all water closets, galleys and to the firemen's and crew's lavatories and showers.

The fresh-water system is supplied by a gravity tank on top of the deck house, filled by a fresh-water pump located in the engine room. This pump also supplies fresh water to the hot-water heater in the engine hatch, and thence to the various lavatories fitted for hot water. The hospital, all bath tubs, wardroom and warrant officers' showers, are fitted with hot and cold fresh water, also one shower in the firemen's washroom. The firemen's and chief petty officers' washbasins have cold fresh water, and there is an independent cold fresh-water faucet in the crew's washroom. The galleys, pantries and bakery have fresh-water connections.

The firemen's and crew's washrooms have two steam connections each for heating water in buckets, and the sinks in the galleys, pantries and bakery are provided with steam pipes for heating the water.

The ship's fresh-water tanks are located on the lower deck aft. They have filling connections from the distilling apparatus and the ship's side, and suction connections to the fresh-water pump in the engine room.

MAIN ENGINES.

The main propelling machinery consists of two vertical, inverted, direct-acting, three-cylinder, triple-expansion engines, placed abreast, port and starboard, in a common compartment, as shown in Figure 2. The engines turn outboard when running ahead. They are designed to develop about 6,700 I.H.P. when running at 95 revolutions per minute, with a steam pressure at the H.P. valve chest of 195 pounds gage.

The sequence of cranks is H.P., I.P. and L.P., all crank angles being 120 degrees.

The cylinders are of cast iron, the H.P. alone being fitted with liners, and none are jacketed.

The housing and bedplates are of cast iron, the former of

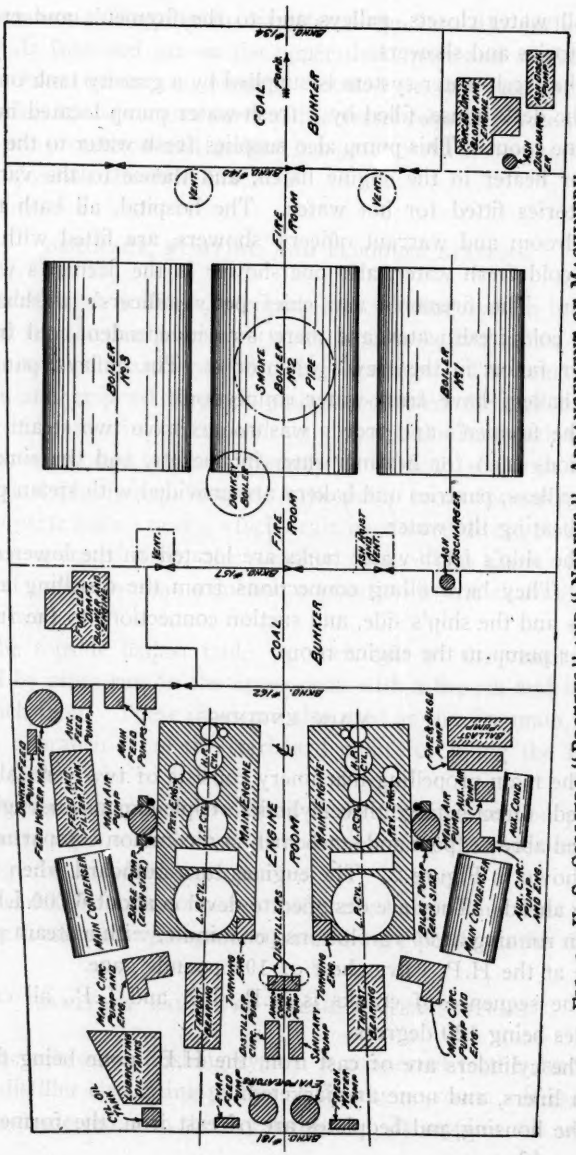


FIG. 2.—U. S. COLLIERS "PROTEUS" AND "NEREUS." ARRANGEMENT OF MACHINERY.

the inverted Y-frame type bolted to the cylinders and bedplates at top and bottom, respectively, and carrying the crosshead guides. The latter are of the box-section type, faced for the reception of the housings and supporting the main bearings, which are lined with white metal.

All pistons are of cast iron of the flat box-section design, fitted with packing rings and followers.

The piston rods and connecting rods are of forged steel. To the former are secured forged-steel crossheads of the double-slipper type, which in turn carry the crosshead slippers, of cast iron and lined with white metal, on both the go-ahead and backing faces.

The valve gear is Stephenson double-bar links, with linking-up screws for changing the point of cutoff. The H.P. and I.P. cylinders have one piston valve each, and the L.P. cylinder a double-ported slide valve. All valves are provided with balance cylinders, that for the L.P. slide valve being of the Improved Lovekin Assistant Cylinder type. The eccentric rods and valve stems are of forged steel, actuated by cast-iron eccentrics secured to the crank shafts. The eccentric straps are of cast steel lined with white metal.

All piston rods and valve-stem stuffing boxes are metallic packed.

Reversing Gear.—Each engine is provided with a reversing engine of the direct-acting type connected through connecting rods to the reversing-shaft arms, the shaft in turn connecting to the links by arms and suspension rods. The gear is controlled by a floating lever operated at the working platform.

Turning Gear.—The customary turning gear is fitted on each engine, consisting of a single-cylinder engine with cylinder 8 inches diameter by 6 inches stroke, driving an intermediate worm shaft, which engages a worm wheel driving a shaft connected to a secondary worm driving a worm wheel attached to the main-engine crank shaft.

Lubricating Gear.—All working and moving parts of the main engines are efficiently lubricated by wick-feed distribu-

tion boxes located on the main cylinders and fitted with brass tubes leading to the various parts requiring lubrication.

Water Service.—A water service is provided for the main bearings, crank pins, crosshead guides and pins, and the thrust bearings. Cooling water for the guides and crosshead pins is taken from the sanitary system and that for the other parts from the main circulating pumps.

Main Engine Data.

Diameter of H.P. cylinder, inches	26
I.P. cylinder, inches	43½
L.P. cylinder, inches	74
Stroke, inches	48
Piston rod, diameter, inches	6
Connecting rod, diameter, crosshead end, inches	5¾
crank end, inches	7¼
length between centers, inches	108
crank ratio	1:4.5
Diameter, throttle valve, inches	9
1st receiver pipes (2), inches	13
2d receiver pipes	none fitted
main exhaust pipe, inches	26

SHAFTING AND BEARINGS.

There are two lines of shafting of three sections each supported by proper bearings. The crank shafts are of the built-up type, and of solid forged steel throughout. The thrust and tail shafts are solid forged steel, the latter being composition cased in wake of the stern tube and bearings.

The crank-shaft couplings and forward coupling of the thrust shaft are of the ordinary disc type, forged solid with the shafts, and that between the thrust and tailshafts is of the split-sleeve type, of cast steel, secured to the shafts by four feather keys and twelve bolts each.

Shaft Data.

Crank shafts, diameter, inches	14½
length, feet and inches	23–03¾
number of cranks	3
throw of cranks, inches	24
angle between cranks, degrees	120

Crank pins, diameter, inches	14½
length, inches	14
Coupling discs, diameter, inches	28½
thickness, inches	04
bolts, number each coupling	6
diameter at face of coupling, inches	03½
Thrust shafts, diameter, inches	14½
length, feet and inches	15–08
collars, number	10
thickness, inches	02¼
space between, inches	05
outside diameter, inches	23½
inside diameter, inches	14½
bearing surface, sq. ins	2,686.1
Tail shafts, diameter, inches	15¼
length, feet and inches	48–00

Bearing Data.

Crank-shaft bearings (White metal lined):	
Number, each shaft	6
Diameter, inches	14½
Length, inches	3 of 15, 2 of 18 and 1 of 20
Thrust bearings (White metal lined bearings and shoes):	
Diameter, inches	14½
Length, inches	15
Thrust shoes, number each	10
effective surface, sq. ins	1,808.7
Stern tube bearings (Lignum vitae lined):	
Forward, diameter, inches	16¾
length, inches	30
After, diameter, inches	16⅞
length, inches	36
Strut bearings (Lignum vitae lined):	
Diameter, inches	16⅞
Length, inches	60

PROPELLERS.

There are two true-screw three-bladed propellers of the adjustable-pitch and detached-blade type. The hubs are of semi-steel and the caps of cast iron. The blades are of manganese bronze secured to the hubs by seven studs each. The propellers have a taper fit on the tail shafts, and are secured by a key and cast-steel nut.

Propeller Data.

Diameter, feet and inches	16–06
Pitch as set, feet and inches	16–05
Pitch	adjustable from 14.21 to 18.62
Ratio of diameter to pitch	0.9954
Projected area, square feet	79.11
Helicoidal area, square feet	90.6
Disc area, square feet	213.8108
Height of lower tip of blade above keel, inches	13.25
Immersion of upper tip of blade at load draught, inches	118.75

MAIN CONDENSING APPARATUS.

Main Condenser.—There are two independent, cylindrical, surface, main condensers located one outboard of each main engine. The shells and heads are of cast iron, tube sheets of rolled brass, and tubes of solid-drawn brass, No. 16 B.W.G. thick, 5/8-inch outside diameter and 8 feet 6 inches long between tube sheets. The lower nest of tubes is expanded in the after tube sheet and secured in the forward tube sheet by the usual screw glands and packing. The upper nest of tubes is fitted in reverse manner. There are 3,239 tubes in each condenser, giving a total cooling surface in each of 4,500 square feet.

Main Circulating Pump and Engine.—The circulating water is supplied each condenser by a double-inlet cast-iron centrifugal pump, having a composition runner 42 inches in diameter. The suction and discharge connections are 16 inches in diameter. Each pump is driven by a single, vertical, reciprocating engine, cylinder 8 inches diameter by 10 inches stroke.

Main Air Pumps.—The main air pumps, one for each condenser, are attached to the main engines and operated from the I.P. crossheads, by the customary levers and rock shaft. They are of the Edwards type, and have 26-inch single water cylinders by 21-inch stroke. The pump body and buckets are of cast iron, brass lined and fitted with brass valves throughout.

Feed and Filter Tank.—A feed and filter tank is located

in the forward port end of the engine room. The filter is divided into four chambers filled with filtering material, and fitted with partition plates so arranged that the entering water will flow alternately under and over the plates, leaving the filter over the top of the last plate, thus assuring the filtering material being always submerged.

ENGINE-ROOM AUXILIARIES.

Bilge Pumps.—There are two bilge pumps of the plunger type, 5 inches diameter by 21 inches stroke, attached to each main air pump and driven from their crossheads.

Auxiliary Condenser.—There is one auxiliary condenser of cast iron with rolled-brass tube sheets. It contains 856 seamless-drawn brass tubes of same size as those of the main condensers. Its cooling surface is 901 square feet.

Auxiliary Circulating Pump.—The auxiliary condenser is provided with an independent centrifugal circulating pump, with 32-inch runner, driven by a single-cylinder, 5-inch by 6-inch engine. The pump casing is of cast iron and the runner brass.

Auxiliary Air Pump.—One vertical, simplex, double-acting, featherweight air pump of the Blake type, is provided for the auxiliary condenser. The steam cylinder is 7½ inches diameter, air cylinder 14 inches diameter, by a common stroke of 10 inches.

Main Feed Pumps.—There are two main feed pumps located on the forward bulkhead of the engine room, port side. They are Blake, vertical, simplex, double-acting pumps, with 14-inch steam cylinder, 9-inch water cylinder by 24 inches common stroke. Each pump draws from the main feed tank and discharges to the main boilers through the feed-water heater and main feed line or via auxiliary feed line by-passing the heater.

Auxiliary Feed Pump.—An auxiliary feed pump is located just outboard of the main feed pumps. It is of the same de-

sign and size as the former. In addition to the connections noted for the main feed pumps it has suctions from the main condensers, boilers and reserve feed tanks, and discharges overboard and to the main feed tank.

Donkey-Boiler Feed Pump.—A small Blake, horizontal, duplex, double-acting feed pump is provided for the donkey boiler. It has 4½-inch steam cylinders, 2¾-inch water cylinders and a common stroke of 4 inches. It has suctions from main feed tank and reserve feed tanks, and discharges to the donkey boiler and the auxiliary feed main.

Fire and Bilge Pump.—A Blake, horizontal, duplex, double-acting, fire and bilge pump is provided, with 10-inch steam cylinders, 7-inch water cylinders and a common stroke of 12 inches. The pump has suctions from sea, drainage system and engine-room bilge, and discharges to the fire main and overboard.

Ballast Pump.—The ballast pump is of the Blake, horizontal, duplex, double-acting type, with 14-inch steam and water cylinders and common stroke of 12 inches. The pump has suctions from the sea, ballast system and drainage system, and discharges to the fire main, overboard, ballast system and main condenser circulating water.

Sanitary Pump.—A Blake, horizontal, duplex, double-acting pump is provided for the sanitary system. It has 6-inch steam cylinders, 5¾-inch water cylinders and a common stroke of 6 inches. It has a suction from the sea and discharges to the sanitary system, engine-water service and distillers, and to the fire main via the sanitary system.

Fresh-Water Pump.—The fresh-water system is provided with a Blake, horizontal, duplex, double-acting pump, with 5¼-inch steam cylinders, 4¾-inch water cylinders and common stroke of 5 inches. It has a suction from the fresh-water tanks and discharges to the gravity tank, on top of the deck house, and to the hot-water heater in the engine hatch.

Feed-Water Heater.—A Reilly multicoil feed-water heater is located in the port forward corner of the engine room,

above the feed pumps. It is connected to the main feed line only. The heating agent is the exhaust steam, a back pressure being kept in the auxiliary exhaust line for this purpose by means of a spring-relief valve at each condenser connection, opening toward the condenser.

BOILERS AND APPURTENANCES.

Main Boilers.—There are three main boilers, of the horizontal, double-ended, Scotch type, arranged abreast in one compartment. Each furnace has an independent combustion chamber. The general particulars of the boilers are given below.

Donkey Boiler.—A donkey boiler of the vertical, cylindrical, fire-tube type, is located in the boiler hatch, above the main boilers at the berth-deck level. The general characteristics of the boiler are given below.

Boiler Data.

	Main (each).	Donkey.
Working pressure, pounds gage	200	200
Mean diameter, feet and inches	15–09	7–00
Length of shell, feet and inches	21–05½	....
Height, external, feet and inches	.....	11–00
Thickness of shell, inches	01 9/16	00 13/32
Furnaces, type	Morison corrugated	Cylindrical
number	8	1
diameter, inside, feet and inches	3–04	6–02
thickness, inch	00 17/32	00 7/16 (stayed)
Grates, length, feet and inches	5–04½	circular
width, inches	40	6′ 1″ diameter.
Grate surface, square feet	143.33	30
Heating surface, square feet	6,164	628
Ratio grate surface to heating surface	1:43	1:21
Clear area through smoke pipe, square feet	85	4.91
Clear area through smoke pipe to grate area	5.06:1	6.11:1
Tubes, material	charcoal iron, lap welded	
number, ordinary	332	216
stay	132	55
diameter, all, inches	02¾	02
thickness, ordinary, B.W.G.	11	12
stay, inches or B.W.G.	00 5/16	08
length between tube sheets, ft. and ins	7–07	5–03 5/8

	Main (each).	Donkey.
Diameter, boiler stop valve, inches.....	6 & 9*	03
safety valves, inches	04½ triple	02½
feed, stop and check valves, inches.	03	01½
bottom-blow valves, inches.....	02	01
surface-blow valve, inches.....	01½	.....

* Each outboard boiler has a 9-inch stop valve and the center boiler two of 6 inches each.

Uptakes and Smoke Pipes.—The main boilers are connected by suitable uptakes to one smoke pipe, 10 feet 9 inches diameter by 90 feet high above the grates. The uptakes and smoke pipes are double cased, with air space between casings. The smoke pipe is stayed by ten wire-rope guys, arranged in two rows, upper and lower, of four and six guys, respectively.

On the front of the smoke pipe is a ladder, extending from the top of the boiler hatch to the top of the pipe, also a whistle and a siren located about 15 feet from the top of the pipe, and on the rear is a 14-inch escape pipe.

The donkey-boiler smoke pipe and galley pipe, 30 inches and 11 inches diameter, respectively, are led inside and to the top of the main smoke pipe.

FIREROOM AUXILIARIES.

Forced-draft System.—A closed ash pit, heated-air, forced-draft system is installed for the main boilers. The air is supplied by two 60-inch Sturtevant, double-inlet, multivane fans, each driven by a vertical, single steam engine, with 7-inch steam cylinder by 4-inch stroke. The blowers are located as shown in Fig. 2. The air is drawn from the firerooms and delivered to the boilers through ducts, connected to heater boxes in the uptakes, where it is heated before delivery to the ash pits.

Ash Dischargers.—Two under-water, horizontal, hydraulic, ash dischargers are installed, one in each fireroom. The apparatus is fully described in an article by Mr. F. P. Palen, appearing on page 366, August number, of this volume of the JOURNAL, to which the reader is referred.

Ash Hoist.—In addition to the ash dischargers mentioned in preceding paragraph, the starboard ventilator in the after fireroom is arranged for hoisting ashes in a bucket by means of a steam ash hoist of the ram type.

MAIN STEAM PIPING.

The main steam piping is of seamless-drawn steel tubing. It is 9 inches in diameter and leads aft from the boilers to the engines in two symmetrical lines, port and starboard. Steam is supplied through a 9-inch connection from each of the outboard boilers, and two 6-inch branches from the center boiler. The mains have a 7-inch cross-connection in the engine room. Stop valves are fitted at the forward engine-room bulkhead, at the boilers and in the cross-connection.

AUXILIARY STEAM PIPING.

The auxiliary steam piping is in two distinct circuits as given below. It is of seamless-drawn steel, and that exposed to the weather is galvanized.

From the main steam pipes in the engine room, with stop valves at the mains, 5-inch branches form a common loop around the engine room, reducing in size as they lead aft. From these pipes branches are taken to the various engine-room auxiliaries, distilling apparatus, refrigerating and dynamo plants, steering engine, capstan and after fireroom blower. This line is also supplied by a 3-inch connection from the donkey boiler.

In the fireroom there is a 6-inch branch from each main steam line, with stop valves at the lines, which lead up the boiler hatch and unite into a common 6-inch pipe. From this pipe there are two branch connections, one to the forward blower, ash-discharger pumps, etc., and the other, of full size with stop valve, is led to the upper deck, where it is carried forward along the deck, port of the coaling hatches, with branches to the coaling winches and windlass engine.

AUXILIARY EXHAUST PIPING.

The auxiliary exhaust pipe is of wrought iron, that exposed to the weather being galvanized. A main, varying in size from 9 to 7 inches in diameter, is led throughout the machinery space, with connections from the various auxiliaries as required. The main is connected to the main and auxiliary condensers, there being a spring-relief valve opening toward the condensers at each connection.

The deck exhaust pipe, ranging in diameter from 5 to 9 inches, is led along the starboard side of the upper deck just outboard of the coaling hatches, with connections from the coaling winches and windlass engine, and down the boiler hatch to the 9-inch auxiliary exhaust line in the fireroom.

BOILER FEED SYSTEM.

The main and auxiliary feed pumps, each, have a 4½-inch suction from the 6-inch feed-tank suction pipe. Each pump has two 4-inch discharge connections, one to the main and the other to the auxiliary feed line. The main feed line is 5 inches in diameter and discharges via the feed water heater to the boilers. The auxiliary feed line is of same size, but does not connect to the heater. All feed connections at the boilers are 3 inches in diameter. The feed discharge pipes are of copper and the suction pipes wrought iron.

INTERIOR COMMUNICATION.

The customary engine and fireroom telegraphs, gongs, voice tubes, etc., are fitted for transmitting orders and signaling to the machinery compartments and other parts of the vessels.

EVAPORATING AND DISTILLING PLANT.

Two evaporators and two distillers are provided, having a combined capacity of 8,000 and 4,000 gallons, respectively, in twenty-four hours. The former are located in the after end

of the engine room, and the latter in the engine hatch. They are of the Reilly multicoil type, and operate in single effect.

Steam for the evaporator is taken off the auxiliary line, and the distiller fresh water is discharged by gravity to the fresh-water tanks and to the fresh-water filling manifold.

Distiller circulating water is supplied by a Blake, horizontal, duplex, double-acting pump, with steam cylinders 6 inches in diameter, water cylinders 5¾ inches in diameter and common stroke of 6 inches. The evaporator feed pump is of same type, with 4½-inch steam cylinders, 2¾-inch water cylinders and common stroke of 4 inches.

ELECTRIC PLANT.

The dynamos are located on the berth deck, starboard of the engine hatch. The installation consists of two horizontal, compound-wound, multipolar, direct-current, 25-kilowatt, General Electric generators, each driven by a cross-compound steam engine, with cylinders 6½ and 10½ diameter by 7-inch stroke. Each generator will deliver at normal load 200 ampères of current at 125 volts, when running 400 revolutions per minute.

REFRIGERATING PLANT.

A Brunswick ammonia compressor, of 2 tons' capacity, direct connected to a 5½ by 7-inch Wach's steam engine, is located on the berth deck, port of the engine hatch, together with condenser, ammonia received and all appurtenances, except the condenser circulating-water pump (Blake, horizontal, duplex, double-acting, with 6-inch steam cylinders, 4-inch water cylinders and common stroke of 6 inches), which is located in the engine room.

The refrigerating rooms are located on the berth deck just below the ice-machinery room.

TRIALS.

The contracts required the following trials for each vessel:

(*a*) A progressive trial over the measured-mile course at the Delaware Breakwater for standardizing the screws, ex-

tending from maximum speed down to a speed of 8 knots; fourteen runs to be made over the course in order to adequately cover the range of speeds desired.

(*b*) A full-speed trial of 18 hours' duration in the open sea in deep water, at the highest speed attainable, which speed shall be not less than an average of fourteen knots an hour, to be determined by the average revolutions of the main shafts, according to the official standardization curve. During this trial the air pressure shall not exceed an average of 1¼ inches of water, and the steam pressure at the H.P. valve chest shall not exceed 195 pounds gage.

(*c*) Complete trials of the coaling appliances and apparatus on the vessel will be made, to demonstrate whether or not they fulfill the guarantees contained in the specifications for the rapid and efficient coaling of vessels alongside or to storage on a wharf.

The mean trial displacement of the vessels shall be that corresponding to the vessels complete, with all permanent and portable fittings of every kind, with all machinery and all auxiliaries, both steam and electric, piping, tools, spare parts, etc., complete, as usually carried on board in service; with outfits of all kinds complete; and with 12,500 tons of bunker and cargo coal, 100 tons of reserve feed water, 20 tons of drinking water, 130 tons of stores and crew.

The trials of the *Proteus* took place in June and those of the *Nereus* in September of this year. Generally fair weather prevailed, and the trials were satisfactorily completed, with all requirements exceeded.

Standardization Trials.—The standardization trials were run on the Delaware Breakwater measured-mile course, on the dates noted in Tables I and II. Each vessel made fourteen runs over the course at various speeds, but in the case of the *Nereus* runs Nos. 10 and 11 were thrown out; the tide changing during these runs, rendering the data uncertain. Tables I and II give the principal data obtained,—from which the curves, Figure 3, were plotted. From the official curves it was

Number of Run	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Time on Course: Mins.	6	8	6	5	4	5	4	4	4	4	3	4	4	3
Secs.	55.5	17	21.9	56.5	39.1	43.2	4.4	46	10.6	12.7	54.6	4.5	2.7	57.2
Revs. to go 1-Knot:														
Starbd. Engine	382.0	464.4	355.9	469.1	366.1	457.9	377.5	439.5	387.4	426.8	398.5	412.6	409.3	405.8
Port Engine	385.9	465.7	357.6	475.2	365.8	456.5	383.2	445.0	393.1	439.2	411.2	423.5	422.9	415.6
Mean	384.0	465.1	356.8	472.2	366.0	456.9	380.4	442.3	390.3	433.0	404.9	418.1	416.1	410.7
Revs. per Minute:														
Starbd. Engine	55.16	56.06	56.01	78.92	78.70	79.95	92.57	92.19	92.73	101.35	101.92	101.52	101.22	102.46
Port Engine	55.74	56.21	56.27	79.95	78.65	79.01	93.97	93.37	94.10	104.29	105.17	103.98	104.58	105.15
Mean	55.45	56.14	56.14	79.43	78.67	79.48	93.27	92.78	93.42	102.82	103.55	102.75	102.90	103.81
Indicated Horse Power:														
Starbd. Engine	643	666	621	1782	1811	1790	2697	2801	2952	3782	3961	3905	3840	3891
Port Engine	651	625	744	1707	1699	1697	2843	2747	2781	4009	3999	3915	4046	3946
Total	1294	1291	1365	3439	3510	3487	5540	5548	5733	7791	7960	7720	7886	7837
Speed in Knots	8.464	7.243	9.427	10.098	12.899	10.490	14.730	12.587	14.366	14.246	15.345	14.726	14.833	15.177

TABLE I.—STANDARDIZATION TRIAL DATA, U. S. F. C. "PROTEUS."

Number of Run	1	2	3	4	5	6	7	8	9	12	13	14
Time on Course: Mins.	5	9	5	6	4	6	4	4	4	3	4	3
Secs.	41.2	59.5	59.2	25.9	49.7	16.5	5.5	49.2	15.7	54.8	22	41.1
Revs. to go 1-Knot:												
Starbd. Engine	321.75	570.05	333.55	474.90	357.30	466.65	378.66	432.40	382.80	390.00	439.90	370.35
Port Engine	312.45	560.35	331.40	468.45	351.40	465.25	370.60	434.00	387.05	392.65	439.80	373.60
Mean	317.10	565.20	332.47	471.65	354.35	465.95	370.63	433.20	384.93	391.33	439.85	372.21
Revs. per Minute:												
Starbd. Engine	56.581	57.031	55.900	73.839	73.948	74.407	90.567	89.729	89.849	99.654	100.744	100.569
Port Engine	54.944	56.060	55.539	72.836	72.776	74.184	90.555	90.070	90.835	100.325	100.835	101.542
Mean	55.743	56.545	55.719	73.337	73.387	74.295	90.561	89.899	90.342	99.989	100.789	100.955
Indicated Horse Power:												
Starbd. Engine	758	674	657	1480	1457	1465	2739	2611	2579	3443	3463	3458
Port Engine	608	589	606	1352	1266	1354	2273	2469	2648	3467	3536	3546
Total	1366	1257	1263	2832	2723	2819	5006	5080	5227	6910	6999	7004
Speed in Knots	10.551	6.005	10.022	9.329	12.427	9.562	14.664	12.448	14.079	15.332	15.340	15.282

TABLE II.—STANDARDIZATION TRIAL DATA, U. S. F. C. "NEREUS."

	Proteus	Nereus
Date of Trial, 1913	June 27&28	Sept. 3&4
Average R.P.M., Starb'd. Engine	100.86	98.82
Port Engine	102.14	99.27
Both Engines	101.5	99.07
Steam Pressure at Boilers, Pounds Gauge	202.3	197.5
Engines, Pounds Gauge	189.5	192.3
Air Pressure in Ash Pits, Inches of Water	0.89	0.985
Vacuum, Starb'd. Condenser, Inches of Mercury	26.3	26.44
Port Condenser, Inches of Mercury	26.02	26.52
I.H.P., Starb'd. Engine	3473	3345
Port Engine	3734	3558
Total	7207	6904
Mean Draught on Trial, Feet and Inches	27- 2¾	27- 3¾
Corresponding Displacement, Tons	18,933	18,838
Mean Speed in Knots	14.675	14.575
Slip of Propeller, Per Cent. of Own Speed, Starb'd.	10.19	8.97
Port	10.64	9.38

TABLE III.—DATA OF 18-HOURS' FULL-POWER TRIALS, U. S. FLEET COLLIERS "PROTEUS" AND "NEREUS."

found to require an average of 96.2 and 94.55 r.p.m. of both main engines, for the *Proteus* and *Nereus*, respectively, to give the contract speed of 14 knots.

Eighteen-Hours Full-Speed Trials.—The full-speed trials

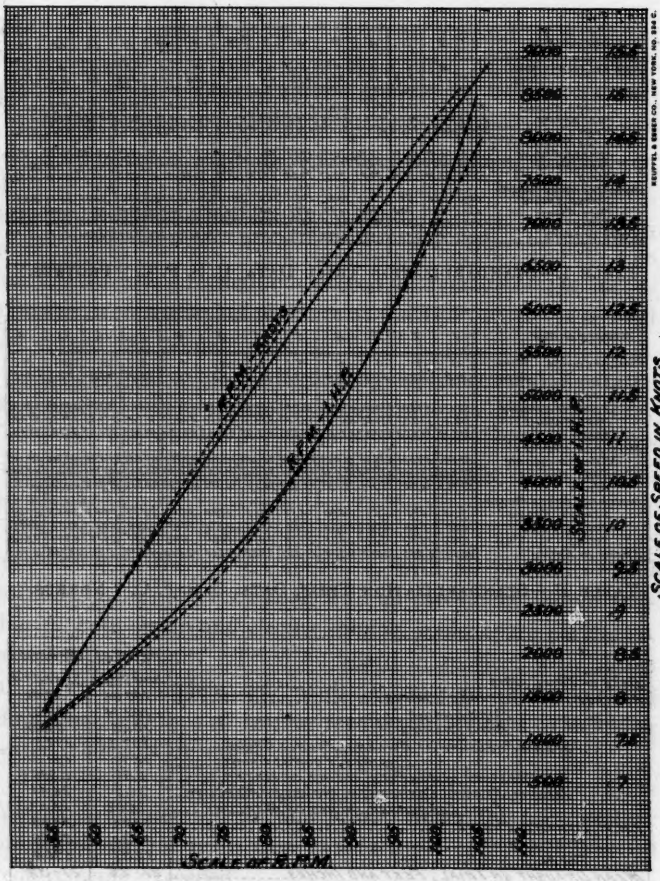


FIG. 3.

were conducted in the open sea on the dates given in Table III, which also gives the averages, for the entire trial, of the principal data obtained. Data was taken every hour. The contract speed of 14 knots was easily exceeded for both vessels. Table IV gives the engine-valve settings.

		Proteus						*Nereus*					
		H.P.		I.P.		L.P.		H.P.		I.P.		L.P.	
Number and type of valves		1-Piston		1-Piston		1-O.P. Slide		1-Piston		1-Piston		1-O.P. Slide	
Dimensions of valves, inches		13 Diam.		25½ Diam.		68 Clear Ports		13 Diam.		25½ Diam.		68 Clear Ports	
Travel of valves, inches		8½		8½		9½		8½		8½		9½	
Inside or outside steam		Inside		Outside		Outside		Inside		Outside		Outside	
		Top	Bot.	Top	Bot.	Top	Bot.	Top	Bot.	Top	Bot.	Top	Bot.
Starboard Engine	Width of port, inches	2 3/4	2 3/4	3	3	3+3½	3+3½	2 3/4	2 3/4	3	3	3+3½	3+3½
	Steam opening, linear, inches	2 3/8	2 1/2	2 9/32	2 13/32	(2)2 9/16	(2)2 23/24	2 3/8	2 1/2	2 9/32	2 13/32	(2)2 3/16	(2)2 23/24
	" " , area, sq. ins.	71.2	75	137.1	144.6	308.1	321.8	71.2	75	137.1	144.6	308.1	321.8
	Exhaust opening, linear, ins.	2 3/4	2 3/4	3	3	3+3½	3+3½	2 3/4	2 3/4	3	3	3+3½	3+3½
	" " , area, sq. ins.	82.5	82.5	180.3	180.3	439	439	82.5	82.5	180.3	180.3	439	439
	Steam lap, inches	1 1/8	1 3/4	1 31/32	1 27/32	2 3/16	1 43/64	1 1/8	1 3/4	1 31/32	1 27/32	2 3/16	1 43/64
	Exhaust lap, inches	− 3/16	+ 3/8	0	+ 17/32	0	+ 45/32	− 3/16	+ 3/8	0	+ 17/32	0	+ 45/32
	Steam lead, linear, inches	23/64	31/64	1/2	5/8	43/16	1/8	23/64	31/64	1/2	5/8	43/16	1/8
	Cut-off, decimal of stroke Max.	79.9	71.2	78.6	70.5	77.6	67.2	79.9	71.2	77.3	69.2	76.4	66
	Cut-off, decimal of stroke Min.	56	47.7	54.2	44.5	51.6	40.1	56.3	48	54.4	44.8	53.1	42.7
Port Engine	Width of port, inches	2 3/4	2 3/4	3	3	3+3½	3+3½	2 3/4	2 3/4	3	3	3+3½	3+3½
	Steam opening, linear, inches	2 3/8	2 1/2	2 9/32	2 13/32	(2)2 9/16	(2)2 23/24	2 3/8	2 1/2	2 9/32	2 13/32	(2)2 9/16	(2)2 23/24
	" " , area, sq. ins.	71.2	75	137.1	144.6	308.1	321.8	71.2	75	137.1	144.6	308.1	321.8
	Exhaust opening, linear, ins.	2 3/4	2 3/4	3	3	3+3½	3+3½	2 3/4	2 3/4	3	3	3+3½	3+3½
	" " , area, sq. ins.	82.5	82.5	180.3	180.3	439	439	82.5	82.5	180.3	180.3	439	439
	Steam lap, inches	1 1/8	1 3/4	2	1 27/32	2 3/16	2	1 1/8	1 3/4	2	1 27/32	2 3/16	2
	Exhaust lap, inches	− 3/16	+ 3/8	0	+ 17/32	0	+ 1/2	− 3/16	+ 3/8	0	+ 17/32	0	+ 1/2
	Steam lead, linear, inches	11/32	15/32	15/32	19/32	3/4	45/16	11/32	15/32	15/32	19/32	3/4	45/16
	Cut-off, decimal of stroke Max.	80.2	75.3	77.9	69.5	76.6	67.7	78.8	73.9	78.2	70	76.8	68
	Cut-off, decimal of stroke Min.	56	47.9	53.2	44.5	53.6	44.5	56	47.9	53.3	44.5	51.8	42.7

TABLE IV.—VALVE SETTINGS ON TRIALS.

TEST OF COALING GEAR.

The test of the coaling gear and appliances was conducted on June 30 and July 1, 1913, for the *Proteus*, at the works of the contractors, and that on the *Nereus*, at the Navy Yard, Norfolk, Va., on September 5, 1913.

On the *Proteus*, a two-hours' coaling test was conducted at one hatch for determining the capacity of the gear, discharging into a lighter secured alongside. The total coal delivered in two hours was 269 tons, or at the rate of 134.5 tons per hatch per hour, nearly twice the guarantee of 75 tons. Following this test all other hatch gears were tested for strength and operation, using a dead weight as required by the contract. All gears operated satisfactorily.

The two-hours' capacity test of one hatch on the *Nereus*, exceeded the requirements by a greater margin than that on the *Proteus*. So satisfactory was this test that at the end of one hour and a quarter operation it was discontinued, in view of the excellent operation and great excess of coal discharged into the barge at the ship's side; the average rate of discharge being 144.4 tons per hour. The test of the gear at other hatches, for strength and operation, was satisfactorily conducted at the works of the contractors, previous to the capacity test.

RADIATED AND RECEIVED ENERGY IN RADIO-TELEGRAPHY.

By L. W. Austin.

Read before The American Philosophical Society April 19, 1913.

Duddell and Taylor* were the first experimenters to attempt to determine the laws relating currents in the sending and receiving antennas used in radiotelegraphy. Their first experiments were carried on near London with distances of only a few hundred yards between the antennas. A little later these experiments were repeated on a larger scale on the Irish Sea between a land station and the steamer *Monarch*, the experiments in this case being extended up to about sixty miles. Their work served to show that up to the distances mentioned the received current fell off directly in proportion to the distance in accordance with the Hertzian equation for the electric force in the equatorial plane of an oscillator.

The determination of this law at once aroused great hopes in the minds of all workers in radiotelegraphy for the establishment of long-distance communication. It was well known that with 2 kw. and with moderate sized antennas it was quite possible to send messages over distances of over three hundred miles in the daytime. From this it was easily calculated in accordance with the Duddell and Taylor law, that it would be necessary to use only 10 kw. with antennas 400 feet high to carry on communication up to 3,000 miles. When the attempt was made, however, it was found that only on exceptionally favorable nights was any communication at all possible, even with two or three times the calculated power, and of course none at all in the daytime. This showed at

*Duddell and Taylor, "Electrician," 55, p. 260, 1905.

once that the Duddell and Taylor law was not applicable at great distances, and it began to be assumed that for communication over water an absorption existed similar to that which had long been recognized in overland communication.

In 1909–10 the United States Navy carried on experiments between the high-power Fessenden station at Brant Rock and the scout cruisers *Birmingham* and *Salem*.* In these experiments regular day communication† was obtained up to 800 miles between the ships, and about, 1,200 miles between the high-power station and the ships. Quantitative experiments on the effect of the height of sending and receiving antennas were also carried on at this time, which verified the results of Marconi, Duddell and Taylor, and Pierce. The results of all this work were finally summarized in the formula

$$I_R = 4.25 \frac{h_1 h_2}{d\lambda} I_s e^{-\frac{ad}{\sqrt{\lambda}}}, \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where I_R is the receiving antenna current, I_s the sending antenna current h_1 and h_2 the heights to the centers of capacity of the two antennas, λ the wave length, and d the distance; the currents being measured in ampères and the length in kilometers. In this formula the resistance of the receiving antenna was arbitrarily taken as 25 ohms, that being the resistance of the Brant Rock station under the conditions of experiment. That the resistance was the same at both wave lengths used (1,000 meters and 3,750 meters) was due to the fact that a series condenser was used in the Brant Rock antenna at the shorter wave length. On the ships, however, there was undoubtedly a very considerable difference in resistance at the different wave lengths. As a matter of fact, we have never had an opportunity to measure accurately the antenna resistance on these ships. From measurements on other ships, however, it is estimated that the antenna resistance at 1,000 meters would be from 15 to 18 ohms, while at 3,750 meters it would probably

*Bulletin Bureau of Standards, 7, p. 315, 1911.

†Night signals, while generally stronger than those in the daytime, are freakish and irregular and unfitted for quantitative comparisons.

be about 35 ohms. No more quantitative work at long distances was carried on by the Navy Department until the autumn of 1912, although in the meantime a number of observations were made at moderate distances which all tended to verify the general accuracy of our formula. The new series of experiments has been made in connection with the high-power naval station at Arlington, Va. This station was equipped by the National Electric Signaling Co. with a 100-kw. rotary-gap sending set, and was intended for communication with the Canal Zone and with the fleet in the North Atlantic Ocean. The original plan for the antenna as submitted by the National Electric Signaling Co. showed an umbrella supported by a single tower 600 feet high. The experiments at Brant Rock, however, showed the experts of the Navy Department that an umbrella antenna gave a center of capacity too low for the most effective working. In fact, comparative results indicated that the effective height was but little if any higher than the bottom of the umbrella, about 150 feet in the case of the Brant Rock tower, although the total height was 420. For this reason the Arlington station has been supplied with a platform antenna supported by three towers about 400 feet between centers, one being 600 feet high and the other two 450 feet. The antenna has been put up in sections and consists of two flat-top antennas 350 feet long, and one 315 feet long. These are 88 feet wide with 23 wires each. The triangular space between the flat tops is filled in with a triangular fan of 25 wires supported independently of the flat-top sections. The vertical portion of the antenna consists of a fan of 23 wires, 88 feet wide at the top, narrowing to 10 feet at 75 feet above the earth, from which point the wires are brought down in a cage of the Fessenden type. The capacity of this antenna is 0.01 m.f., its natural period approximately 2,100 meters and its height to the center of capacity 400 feet. The ground system consists of a radiating network of wires covering the space between the triangle of towers and extending to some distance outside. The towers were built so that they were insulated from the earth with

switches by which they could be connected with the ground net system. With the towers insulated, the antenna resistance exclusive of the inductance at a wave length of 4,000 meters is approximately 8 ohms. Grounding the towers reduces the resistance to 1.8 ohms, and, curiously enough, no perceptible difference in capacity is observed, nor is the natural period changed by more than a few meters. Theoretically it is difficult to understand how this great difference in antenna resistance can be produced without changing the field distribution so as to vary the capacity and wave length, but what is still more remarkable is that it is found that the ratio between the current in a receiving antenna a few miles distant and the sending current at Arlington remains absolutely unchanged whether the towers are grounded or insulated. But since the sending current with the towers grounded is approximately 50 per cent. larger than when the towers are insulated, they are always kept grounded. For receiving at Arlington there is practically no difference.

Referring again to the formula for the received current

$$I_R = 4.25 \frac{h_1 h_2}{\lambda d} I_s e^{-\frac{\pi d}{\nu \lambda}},$$

it will be noticed that, if we disregard the absorption term, it bears a striking resemblance to the Hertzian equation for the amplitude of the electric force in the equatorial plane of an oscillator.* This equation in the form given by Zenneck is†

$$E_0 = 2\pi \frac{l I_0}{\lambda d} 3.10^{10} \text{ C.G.S.} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where E_0 is the electric amplitude at the distance d, l the length of the oscillator, and I_0 the current amplitude in the oscillator, and was derived for continuous oscillations and for an oscillator consisting of two large spheres connected by thin wires with a spark gap in the middle, an arrangement which

* This applies strictly only to values of d amounting to a large number of wave lengths.
† J. Zenneck, "Lehrbuch der drahtlosen Telegraphie," p. 45.

produces a uniform current distribution throughout the wires. If we substitute the effective values of the electric field E and current I in the antennas, in place of the amplitudes, the equation will, of course, remain true. Therefore, if we are able to determine the length of the Hertzian oscillator which will be equivalent to a wireless antenna, we have at once a very convenient means of calculating the electric field at any distance not great enough to have the absorption come into play. Theoretical formulae for this purpose have been given by Rudenberg,* and attempts have been made to apply them to the case of the scout cruisers *Birmingham* and *Salem* by H. Barckhausen† and myself.‡

The formulae are based on the assumption that if an antenna be erected on a conducting surface, its field will be the same as that of an antenna in space of twice the height, the lower portion being exactly like the real antenna but inverted beneath it; that is, the length of the equivalent

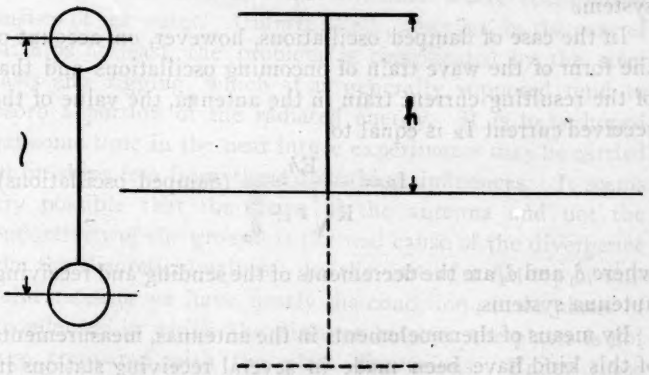


FIG. 1.

Hertzian oscillator will be twice the height from the earth to the center of capacity of the antenna. As Rudenberg observes, however, the imaginary portion does not contribute

* R. Rudenberg, "Ann. d. Phys.," 25, p. 446, 1908.
† H. Barckhausen, "Jahrb. d. drahtlosen Telegraphie," V, p. 261, 1912.
‡ "Journ. Wash. Acad.," I, p. 275, 1911.

to the energy radiated by the antenna. Then since the energy is proportioned to l, the length of the oscillator, squared

$$l^2 = \frac{(2h)^2}{2}, \text{ or } l = h\sqrt{2}.$$

Hence to get the length of the equivalent Hertzian oscillator we must multiply the height h to the center of capacity of the antenna by $\sqrt{2}$. In order to determine the theoretical value of the received current we must determine the electromotive force on the receiving antenna by multiplying the effective value of the field E by the height to the center of capacity of the receiving antenna. If we are dealing with continuous oscillations, the received current will then be given by

$$I_R = \frac{Eh_2}{R} \text{ (undamped oscillations), } \ldots \quad (2)$$

where R is the high-frequency resistance of the receiving system.

In the case of damped oscillations, however, on account of the form of the wave train of oncoming oscillations and that of the resulting current train in the antenna, the value of the received current I_R is equal to

$$I_R = \frac{Eh_2}{R\sqrt{1 + \frac{\delta_1}{\delta_2}}} \text{ (damped oscillations),}$$

where δ_1 and δ_2 are the decrements of the sending and receiving antenna systems.

By means of thermoelements in the antennas, measurements of this kind have been made in several receiving stations in Washington using the high-power station at Arlington and the station at the Washington Navy Yard for sending.*

The results of the calculated and observed values are given in Table I. It is seen that the observed values vary between

*In these experiments the distances between the sending and receiving stations lay between 1.5 and 10 wave lengths. The greatest possible error due to the inapplicability of the inverse distance law to these short distances would be about 10 per cent. No evidence of ground absorption at these distances has been observed.

TABLE I.

Sending station.	Receiving station.	Distance.	Received Obs.	Current Cal.	Obs. / Cal.
		Km.	Amp.	Amp.	pr. ct.
Arlington ($\lambda = 3900$ m.)	Bureau of Standards	7.8	$5.8.10^{-3}$	15.10^{-3}	39
"	Capitol	6.4	12.0	27.5	45
"	Navy Yard	7.2	10.3	17.2	60
Navy Yard ($\lambda = 1000$ m.)	Bureau of Standards	10.0	4.1	7.6	54
"	Capitol	1.9	8.5	15.0	57

40 per cent. and 60 per cent. of the calculated values; that is, the effective length of the equivalent Hertizan oscillator is apparently too great. This may be due either to the shape of the antennas or to the fact that the earth beneath them is not properly conducting as is assumed in the derivation of the formula. If the last supposition is true, a better agreement between the theoretical and observed values ought to be obtained in the case of ships' antennas where the ground consists of sea water. Unfortunately, however, in the case of warships at least, the problem is complicated by the steel masts and rigging, which it is generally supposed tend to absorb a portion of the radiated energy. It is to be hoped that some time in the near future experiments may be carried out on ships free from these disturbing influences. It seems very possible that the shape of the antenna and not the conductivity of the ground is the real cause of the divergence from the theoretical values. In the case of a flat-top or umbrella antenna we have nearly the condition of two plates of a condenser in which the distance between the plates is not large compared with the plate dimensions. Under these circumstances it is certain that the electric field distribution will not be the same as that due to one of the spheres of a Hertzian oscillator placed at the center of capacity of the antenna system. However this may be, the experiments show that the length of the oscillator equivalent to the antenna of a land station is somewhat less instead of greater than the height to the center of capacity.

OBSERVATIONS AT GREATER DISTANCES.

In the Brant Rock experiments already mentioned it was found that for distances of more than 100 miles over sea water a measurable absorption of the radiated energy took place, so that to represent the received current the full form of equation (1) including the absorption factor must be used. In the experiments mentioned, observations were made on the scout cruisers up to about 1,200 miles. The figure (Fig. 2) shows

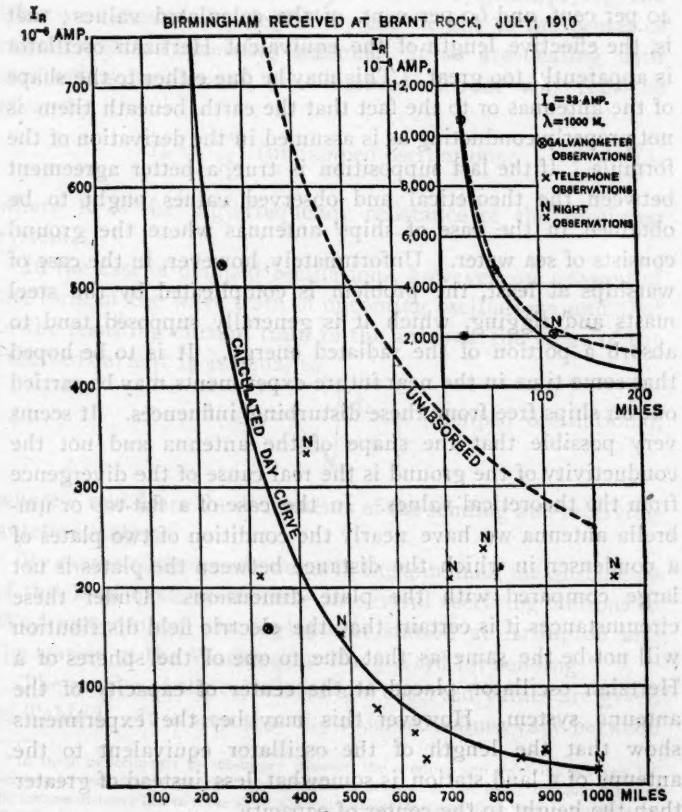
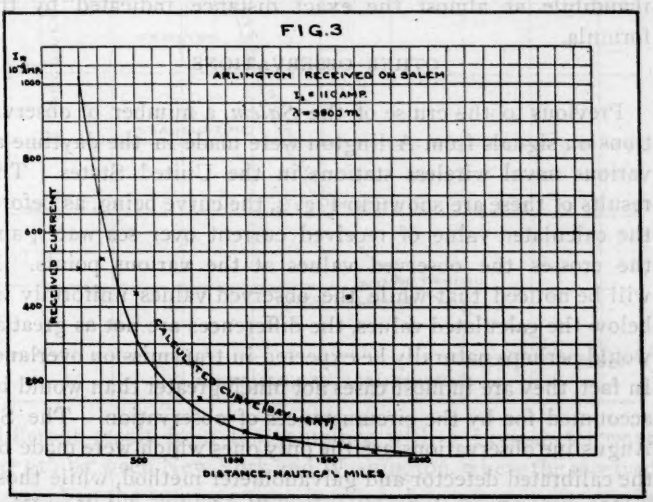


FIG. 2.

that at a distance of 1,000 miles, at a wave length of 1,000 meters, the received current was only one seventeenth of what would have been received if there had been no absorption, and, since the strength of signal in the telephone is proportional to the square of the received current, the signal was reduced to approximately one three-hundredth.

During the months of February and March of this year the cruiser *Salem* was sent on a voyage to Gibraltar for the purpose of carrying out tests with the Arlington station. Successful observations with the electrolytic detector were made in the daytime up to 1,920 nautical miles, while by other detecting devices not sufficiently quantitative for measurement purposes, messages were read up to about 2,100 nautical miles. The results of measurements are shown in Fig. 3. The wave length

FIG. 3



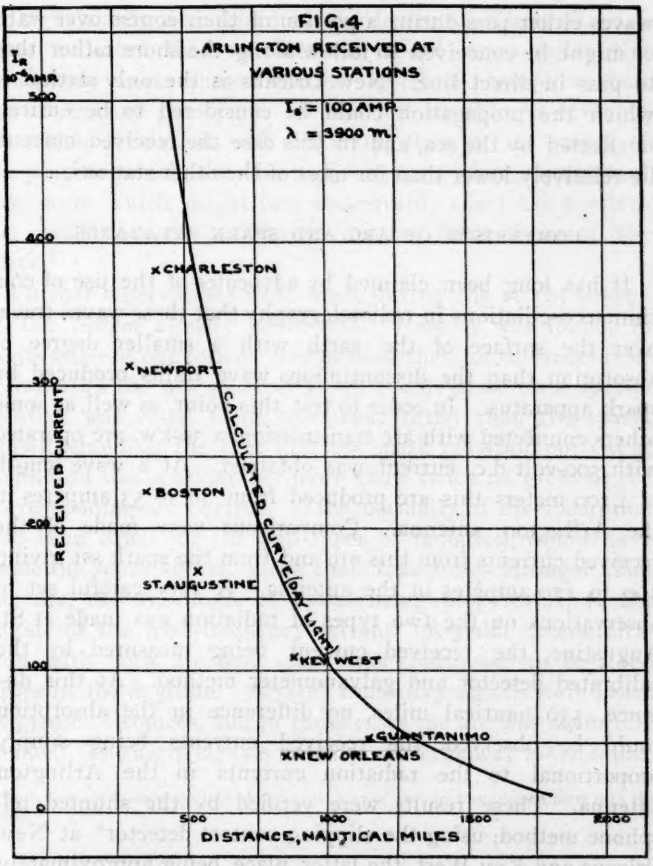
used by Arlington was 3,900 meters, and the average sending current was 110 ampères. The effective height of the Arlington antenna was 400 feet, while that of the *Salem* was taken as 130 feet, this being the value which was used in the calculation of the formula of the Brant Rock test. This is probably somewhat too high but is retained in the present

calculation for purposes of comparison. The curve of the figure is calculated from Tables XVI and XVIa of the article already cited.* The observed values of the received currents, as indicated by the crosses in the figure, were calculated from the audibility measurements made by the shunted telephone method on the electrolytic detector in exactly the same way as in the Brant Rock experiments, except that on account of the increased efficiency of the receiving set, the least audible antenna current was taken as seven microampères instead of ten. The observer was Mr. Lee, who also took the most important observations during the Brant Rock test. Considering the difficulties of taking these measurements, the agreement with the theoretical curve is all that could be desired. It is especially to be noted that the signals became inaudibile at almost the exact distance indicated by the formula.

OTHER OBSERVATIONS.

Previous to the cruise of the *Salem*, a number of observations on signals from Arlington were made in the daytime at various naval wireless stations in the United States. The results of these are shown in Fig. 4, the curve being, as before, the calculated value of received current over sea water, and the crosses the observed values at the various points. It will be noticed that while the observed values uniformly lie below the calculated values, the differences are not as great as would perhaps naturally be expected in transmission overland. In fact, they are in most cases not much greater than would be accounted for by the circumstances of observation. The St. Augustine observations are the only ones which were made by the calibrated detector and galvanometer method, while those at Newport, Boston, Guantanamo, Charleston and Key West were taken on uncalibrated crystal detectors by the shunted telephone method. The results show that for a wave length of approximately 4,000 meters the ground absorption is small, at least for distances less than 1,000 miles. This is a very

*Bulletin Bureau of Standards, 7, p. 315, 1911.



different result from that obtained with a 1,000-meter wave length between New York and Washington, where the received current in the summer time is reduced to 10 per cent. of the value which it would have over salt water.* Of course, it must be considered, in the Arlington experiments just mentioned, that most of the stations lie on the sea coast, so that the

*For great distances over sea, and distances of more than 100 miles over land, long waves should be used on account of their decreased absorption; while for short distances shorter waves are better on account of their more vigorous radiation.

waves either pass during a portion of their course over water or might be conceived to follow along the shore rather than to pass in direct line. New Orleans is the only station in which the propagation could be considered to be entirely unaffected by the sea, and in this case the received currents lie relatively lower than for most of the other stations.

COMPARISON OF ARC AND SPARK APPARATUS.

It has long been claimed by advocates of the use of continuous oscillations in radiotelegraphy that these waves travel over the surface of the earth with a smaller degree of absorption than the discontinuous wave trains produced by spark apparatus. In order to test this point, as well as some others connected with arc transmission, a 30-kw. arc operated with 500-volt d.c. current was obtained. At a wave length of 4,100 meters this arc produced from 48 to 53 ampères in the Arlington antenna. Comparisons were made of the received currents from this arc and from the spark set giving 100 to 120 ampères in the antenna. A very careful set of observations on the two types of radiation was made at St. Augustine, the received current being measured by the calibrated detector and galvanometer method. At this distance, 530 nautical miles, no difference in the absorption could be observed, the received currents being simply proportional to the radiation currents in the Arlington antenna. These results were verified by the shunted telephone method, using the slipping contact detector* at New Orleans and Key West, the latter place being approximately 900 miles from Washington. The receiving apparatus was then placed on the U. S. S. *Arkansas* and taken to Colon, 1,800 nautical miles from Washington. On the voyage, although the conditions were not favorable for accurate observations, it appeared that during the daytime the arc signals gradually approached those of the spark in intensity. During the two days available for observation at Colon, the

* "Journ. Wash. Acad.," I, p. 5, 1911.

arc signals only were heard in the daytime. These observations indicated that at distances above 1,000 miles the continuous waves show a smaller degree of absorption than the waves from the spark. It was not possible, however, to draw this conclusion with certainty, since at the season of the year in which the observations were taken, exceptional days occur which might very conceivably affect the continuous oscillations in a different manner from those of the spark.*

Further observations were made during the recent voyage of the *Salem* already mentioned. Here it was found, in verification of our former conclusions, that for distances over 1,400 miles the arc as received in the daytime on a special receiver was equal to or somewhat better than the spark, notwithstanding the fact that the spark radiation current at Arlington was considerably more than twice as great as the corresponding arc current. This normally, if the absorption had been equal for the two types of radiation, would have made the spark signals more than four times stronger than the arc, the amplitude of signal being proportional to the square of the high-frequency current. Regular communication with both arc and spark was continued up to 2,100 miles in the daytime. Several times day signals were heard at greater distances, and in these cases the arc was uniformly louder. The night signals were heard all the way to Gibraltar.

*It is frequently observed that at night one type of wave is strengthened more than the other.

THE SEARCHLIGHT, AND THE PRINCIPLES INVOLVED IN ITS CONSTRUCTION AND USE.

By Logan Cresap, Lieutenant, U. S. N., Member.

THE PRODUCTION AND QUALITY OF LIGHT IN AN ARC.

An electric current may exist between two electrodes of different potentials, not in contact themselves, but connected, so to speak, by a conductor of gas or vapor. This phenomenon is, however, divided into two distinct classes, to which have been given the names Disruptive Conduction and Continuous Conduction.

In disruptive conduction the conductor is the gas which surrounds and bridges the gap between the electrodes, and when this gas becomes luminous because of the conduction, the spectrum of the light produced is that of the conducting gas. The most prominent example of this class is the ordinary spark-gap and high-voltage discharge. Another example is the Geissler tube. Any conducting material may be used as terminals to produce this phenomenon, and will not affect the character of the light produced, unless they are decomposed by any heat which may be produced in them or by chemical action of the surrounding gas. This is, however, a condition which is hard to fill, and the terminals gradually disintegrate in disruptive conduction.

Either continuous or alternating current may be used to produce this phenomenon, for in the same gas, with conditions of gas pressure, temperature and length of gap the same, disruptive discharge depends only on the voltage across the terminals. Conduction takes place only after a definite difference of potential exists, and when started the voltage drop between terminals is constant and independent of the current.

In continuous conduction we have an entirely different set of conditions and resultant phenomena. Here the conductor is the vapor of the electrode material, and is formed by the heat of the passing current vaporizing the electrode. The spectrum of the light produced is that of the electrode material and not of the surrounding gas, nor has the surrounding gas any effect on it. The surrounding gas, however, must necessarily affect the *conduct* of this conductor, as it has been displaced by it, and must therefore affect it by changes of pressure and movement.

This column of conducting vapor, or the space between the terminals, with the extreme tips of the terminals is generally referred to as the *arc.*

Disruptive conduction depends solely on difference of potential for its beginning. Continuous conduction depends on the existence of the arc conductor, which must therefore be produced, and which, consequently, is a constant drain of energy.

The arc may be started in several ways; the following two only are of interest to us. If we bring two terminals, between which there is a potential difference, into contact, a current will flow between them. We then slowly separate them. At the instant of separation, the contact point being heated by the consequent resistance, a small quantity of the electrodes will be vaporized, and a minute arc conductor thus established. Further interchange of current and widening of the gap merely enlarges this small arc conductor until a recognized arc is established. Another method of establishing an arc is to raise the potential difference between two separated terminals until disruptive conduction occurs. If the energy of the static spark is sufficient and the difference of potential is maintained long enough, a vapor stream may be formed and the arc started. If after the arc is established the current ceases, even for an instant, the arc conductor collapses and the arc will have to be re-established before current can again flow; thus continuous conduction may be called a continuous-current phenomenon. The ordinary alternating current can

be made to sustain a carbon arc, however, for at the temperature of the carbon arc all gases and vapors have become good conductors, and the voltage necessary to maintain the carbon arc is sufficient to re-start the current after its reversal, through the hot carbon vapor.

The arc conductor, or stream of vapor, issues from the negative terminal, is in rapid motion from it toward the positive terminal, and is probably at nearly the same temperature as the boiling point of the material of which the negative terminal is made. For instance, in an arc in which the positive terminal is copper and the negative terminal magnetite, the column of conducting vapor is solely the vapor from the magnetite. If, however, the positive terminal contains any substance which vaporizes at a temperature below that to which the positive terminal may become heated, the resultant vapors from the positive terminal enter the arc stream and, there becoming luminous, add their spectrum to that of the arc conductor or negative terminal.

While the negative terminal supplies the arc conductor, in general, more heat is liberated at the positive terminal; hence, with the two terminals of the same size and material the positive one will rise to a higher temperature and will consequently waste away faster.

Thus in the magnetite arc mentioned above, if the copper positive is made large enough to prevent its being heated to that temperature at which it will boil, it will not waste away; and if made larger than that so that its temperature can be kept below that of the arc conductors, it will actually increase in size, due to the condensation of magnetite vapor upon it.

In the carbon arc, the one most extensively used, the positive carbon is made larger than the negative to balance this inequality of consumption and for other reasons to be mentioned later.

There are thus two sources of light from an arc. One is the arc conductor itself, which is, as we have seen, a vapor issuing from the negative terminal. In it part of the passing current is converted into radiant energy, part of which is

visible to us as light. The "Luminous Arcs" of everyday use are examples of this kind of light. The arc may be made to give light also by feeding into it vapor from the positive terminal, and this class are called "Flame Arcs." The second method of producing light by the arc is due to the heating of the tips of the terminals to incandescence, and if the material of the terminals is of a highly refractory nature the terminals, principally the positive one, may be heated to such a temperature as to produce a very efficient incandescent light.

Carbon at once assumes the field for this light, for it has many advantages, especially for searchlight work. It has the highest melting point of any element known, and, consequently, when heated to that point, on the tip of an arc terminal, it gives a light of high intensity and concentration, lending itself to location at the focus of a mirror. The light from this high-temperature source is made up principally of the higher frequencies of the visible spectrum, and these, as compared to the lower frequencies, give better illumination at a distance, or, as we may better call it, penetration, for equal power.

As has been pointed out, the light utilized in a searchlight is that given off by radiation from the incandescent tip of the positive carbon; hence it is evident that the quality of this light is practically independent of variations in the chemical composition of the carbon. The only effect such variations might have on the light would be a slight variation in the intensity of the light, due to a slight variation in the temperature of the incandescent tip caused thereby.

THE CARBON ARC AND SOME OF ITS CHARACTERISTICS.

Having started an arc between two carbon electrodes, as explained previously, several facts become apparent after a short period of burning. The positive electrode assumes a cup-like shape, which, because of its similarity, perhaps, to volcanic craters, is called the crater, while the negative terminal becomes somewhat tapered or pointed. The stream of

conducting carbon vapor, in general, leaves the point of the negative, as we saw demonstrated previously, and is projected into the crater of the positive, where it is scattered somewhat like water is scattered in the cup of a Pelton wheel, and mixes and escapes with the vapor which is being constantly evolved around the positive terminal. The positive terminal is thus the one around which the majority of the so-called flame is seen. The positive carbon is, when in operation, at the temperature of boiling carbon, a temperature variously estimated by different authorities. Dewar gives 6,000 degrees C., while Rosetti gives 3,200 degrees C. as the temperature of the positive and 2,500 degrees C. as that of the negative.

The conducting stream is not perfectly constant in shape and location, for as the current is increased the cross-sectional area of the arc stream increases, and as that part of the terminals from which the stream is issuing, or entering, becomes wasted away, the stream seeks other localities where the length of the arc is less. In other words, the conducting stream always seeks the shortest path between the terminals.

With constant current through the arc, the voltage drop across the arc is, except at very short arc lengths, proportional to the arc lengths, or very nearly so. This is probably explained by the assumption that the diameter of the arc stream being proportional to the current, the consequent resistance of the arc stream is closely proportional to the arc length, an assumption not at all unreasonable.

Thus in Fig. 1, with currents of 30, 70, 90, 110 and 130 ampères, the voltage drop across the arc is plotted as a function of the arc length. Here we see that the smaller the current the steeper the curve; or, in other words, a low-current arc consumes greater voltage to bridge a given arc length than does a high-current arc.

It is noticed in Fig. 1 that all the curves, if produced as shown, intersect at a point whose co-ordinates are, voltage 39, and arc length, minus $\frac{1}{8}$ inch. We may thus assume that the voltage drop across the carbon arc is made up of two

parts, one a constant, 39 volts, and the other a variable which is proportional to the length of the arc, plus an additional length of $\frac{1}{3}$ of an inch.

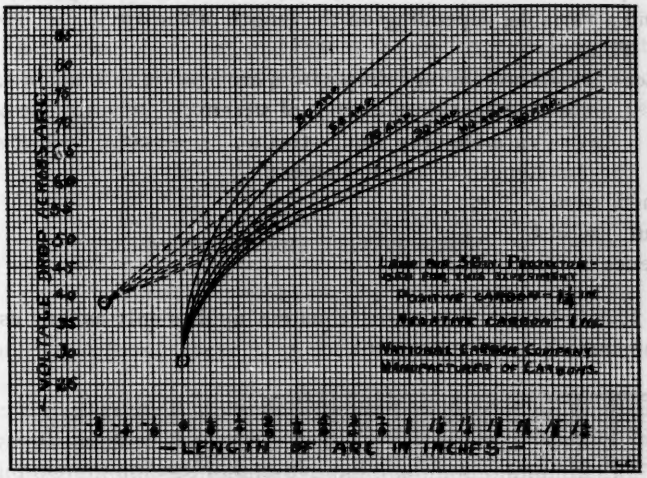


FIG. 1.

We saw in an early part of this paper that continuous conduction depended on the existence of the arc conductor and that its production, consequently, was the source of a constant drain of energy. From the curves of Fig. 1, it is seen that the lowest voltage registered, or, in other words, the voltage necessary to produce or maintain an arc of even the smallest length at any ampèrage, is about 29 volts. This 29 volts, then, represents the expenditure of energy necessary to produce the arc stream and heat the tips of the carbons. The consumption of the remaining 10 volts is probably caused by the interference that the arc stream encounters in penetrating the haze of carbon vapor which surrounds the positive carbon. The fact that, for very short lengths, this additional consumption of energy decreases to zero with decrease of arc length, is probably due to the fact that the negative terminal itself is penetrating into this haze and, hence, saves the arc stream

some of its work. As this variation from the direct relation takes place only in the very short arc lengths, we may eliminate it from our consideration, and assume that the voltage drop across the arc is made up only of the constant 39 volts and a variable, depending on the length of the arc.

Thus:

Let v = Total voltage drop across arc;
v_t = Constant drop at ends of stream;
v_s = Variable drop along stream;
l = Length of arc, in inches;
then $v = v_t + v_s$;
but $v_s = k_1 (l + \frac{1}{3})$;
hence $v = v_t + k_1 (l + \frac{1}{3})$.

It is to be noted that this equation applies only as long as the current remains constant.

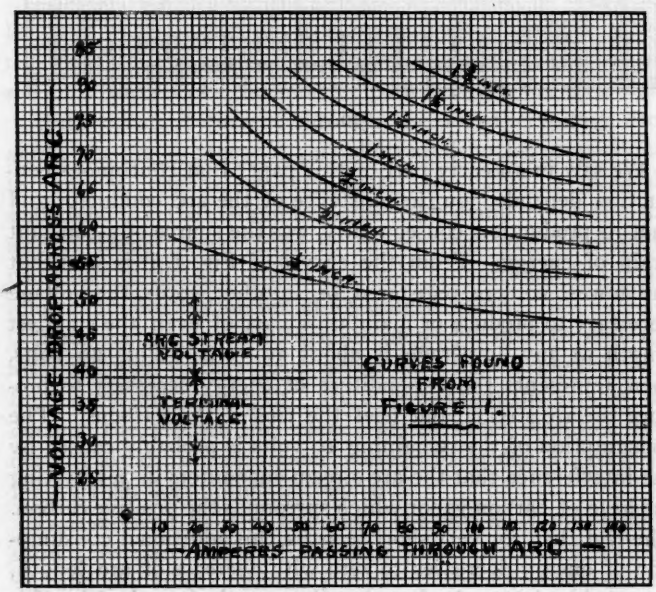


FIG. 2.

Let us now consider the effect of current variation. Plot the arc voltage as a function of the current (from Fig. 1) for any definite arc length, as in Fig. 2, where curves for $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, $1\frac{1}{4}$, $1\frac{1}{2}$ and $1\frac{3}{4}$ inches are plotted. We find that with a fixed arc length, the voltage drop across the arc increases with decrease of current, and that as the arc length is increased the amount of voltage drop is increased. These curves are, except for very short arc lengths, hyperbolas, and may be expressed, where—

c = Current;

v_s = The voltage drop in the stream,
by the formula: $(v_s)^a (c) = (k_2)^a$,

$$\text{or } v_s = \frac{k_2}{(c)^{1/a}}$$

and, as we found above, that, for a constant value of current,

$$v_s = k_1 (l + \tfrac{1}{3}),$$

we may express the voltage of the arc stream as a function of the current and arc length by,

$$v_s = \frac{k (l + \frac{1}{3})}{c^{1/a}};$$

and as $v = v_t + v_s$ we may express the total voltage across the arc by

$$v = v_t + \frac{k (l \times \frac{1}{3})}{c^{1/a}}.$$

Let us, by utilizing the actual results, as shown in Fig. 2, solve this equation for the unknown value of k and a.

We find, for instance, that:

When $l = \frac{3}{4}$ inch, and $c = 130$ ampères, then $v = 57{\cdot}5$ volts, and when $l = \frac{3}{4}$ inch, and $c = 30$ ampères, then $v = 76.0$ volts;

hence we have $$57{\cdot}5 = 39 + \frac{k (\frac{3}{4} + \frac{1}{3})}{(130)^{1/a}}, \quad \ldots \quad (A)$$

and $$76.0 = 39 + \frac{k (\frac{3}{4} + \frac{1}{3})}{(30)^{1/a}}. \quad \ldots \quad (B)$$

Solving these equations we find that

$$\frac{1}{a} = .4727$$

and

$$k = 170.48.$$

Similarly,

When $l = \frac{5}{4}$ inch, and $c = 50$ ampères, then $v = 81.25$ volts; and when $l = \frac{5}{4}$ inch and $c = 130$ ampères, then $v = 66.00$ volts;

hence we have

$$81.25 = 39 + \frac{k\left(\frac{5}{4} + \frac{1}{8}\right)}{(50)^{1/a}}, \quad . \quad . \quad . \quad . \quad (C)$$

and

$$66.00 = 39 + \frac{k\left(\frac{5}{4} + \frac{1}{8}\right)}{(130)^{1/a}}. \quad . \quad . \quad . \quad . \quad (D)$$

Solving these equations we find that

$$\frac{1}{a} = .4686$$

and

$$k = 166.88.$$

As we have taken points from our curves which are widely separated, we may average these results, which will give us, approximately, values as follows:

$$\frac{1}{a} = .47;$$

$$k = 168.5$$

We may then represent the equation of the carbon arc for carbons of the size and quality of those used in the determination of the curves of Figs. 1 and 2, as follows:

$$v = 39 + \frac{168.5\left(l + \frac{1}{8}\right)}{C^{.47}}.$$

With other carbons, with other diameters, and carrying different currents, the above equation remains effective, although it is probable that a decrease of dimensions and current causes a small decrease in the value of the constant k, a fact which is demonstrated by the remarkable coincidence of these results with those obtained in investigations of small arc lamps using from 3 to 9 ampères.

THE DISTRIBUTION AND UTILIZATION OF THE LIGHT IN A SEARCHLIGHT.

As has been stated before, the positive carbon is not only the hottest, but produces the majority, in fact practically all of the light given off in a carbon arc. The positive is consequently made to face the lens of a projector. The quantity of light given off by the positive terminals is proportional to the size of the incandescent spot, while the size of this spot is dependent on the current and to a certain degree on the carbon.

Photometric tests on arcs are extremely difficult, due to the unsteadiness and variations of the arc and the implements for use in such determinations being so liable to error.

It may be stated in general, however, that the intensity of the light of a carbon arc in any fixed direction is proportional to the current, and varies with it directly. This is reasonable to suppose on the theory that the heating effect at the positive terminal is proportional to the current. Thus, as the current increases the area of boiling carbon increases, and naturally in proportion to it. As a matter of fact, the area of the luminous spot has been found to increase a little more rapidly than did the current, and this is explained as follows: The positive carbon is faced with a stream of carbon vapor almost as hot as it is, and consequently the majority of the loss of energy by radiation takes place around the edge of the crater or luminous spot. The ratio between *area* and *circumference* of this crater becomes larger as the area is increased, hence the proportion of the loss of energy by radiation around the edge of the crater becomes less as the current is increased, or the area of the incandescent spot will increase at a faster rate than does the current producing it. The same argument applies to the radiation of light from the incandescent spot, hence it is apparent that the intensity of light will increase faster than the current. The results as given in the table which follows are plotted in Fig. 3 to show this graphically, and are taken from Foster's Electrical Engineer's Pocket Book, 1908.

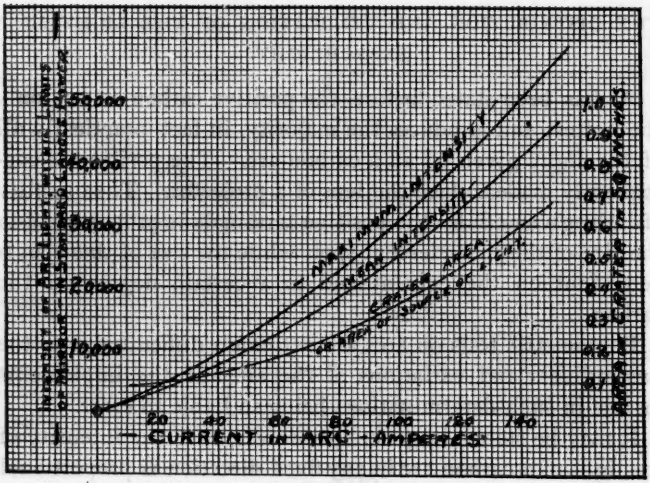


FIG. 3.

If the voltage drop across the arc decreases less rapidly than the intensity increases with increase of current, then the efficiency of the arc increases with the current. As a matter of fact, the intensity of the light does increase more rapidly than the power in the arc, a fact easily seen from a comparison of the curves of Fig. 2 and Fig. 3, or a glance at the table following later. Thus with 30 ampères the candles per watt are 4.8, while with 60 ampères the candles per watt are 5.55.

It is of course true that a light, up to the point of unstability, will give more light as the watts consumed in the arc are increased, but it is erroneous to believe that the quantity of light increases proportionally with the watts across the arc.

While considering light intensity it would be well to form a correct idea of how the measurement of light is stated in units. A candlepower is the illumination, or rather the physiological sensation, given to the eye by a certain light. Thus the unit of light intensity as chosen by convention is the physiological effect exerted on the human eye by five square

millimeters of melting platinum, or by a flame burning a definite chemical compound at a definite rate under definite conditions. If we double the size of this source of light we double the intensity. It is thus apparent that in the carbon arc, increasing the size of the luminous spot increases the light intensity proportionally. This is to be distinguished, however, from increasing the temperature of the luminous spot, for if we increase the temperature we affect the color or frequency of the light and thus change the physiological effect on the eye. We thus see how difficult and really inaccurate it is to compare incandescent light of different frequencies or colors, as the physiological effect on the eye varies with the frequency. At the same time it is easy to see that in the carbon arc where the temperature is practically the same in different arcs the quantity of light varies with the size of the illuminating spot. We are not interested just at present, however, in the intensity of the light in a certain direction, but in the total quantity of light emanating from the source, and this is expressed by including the area of the source. To express the total density of light-flux we adopt a unit called the "Lumen." Unit light-flux density is the light-flux density which gives the physiological effect of one candle at unit distance. The lumen or unit of light-flux is the light passing through unit surface at unit light-flux density. Thus a unit of light intensity of one candle gives, if the light distribution is uniform in all directions, 4π lumens, since the area at unit distance from a point is the area of a sphere, or 4π. Thus by knowing the average light intensity in all directions the light-flux density in lumens is 4π times this average intensity. It is thus easily seen how impractical it would be to rate searchlights by their candle power. It would, however, be advisable, in rating searchlights to introduce the number of ampères used in the light, for it is this figure around which the dimensions and power of the light concentrate.

While no available data of light distribution in the seachlight arc is available, the distribution curve of an arc lamp

shown in Fig 4 will give some idea of how this distribution occurs.

Fig. 4 is a diagram taken from Steinmetz—Radiation, Light and Illumination,—showing the distribution and intensity of light in an arc lamp, in which the carbons are of the same size. The luminous spot is continually wandering around the tip of the positive carbon, and the curve on the right of the axis shows the intensity when the luminous spot is near the observer, while that on the left shows the intensity when the spot is farthest from the observer.

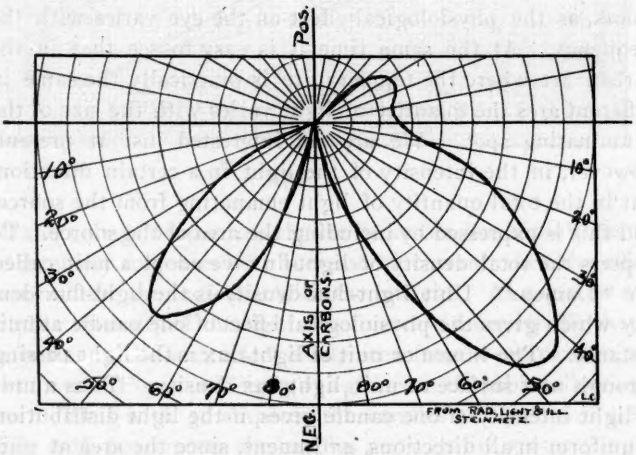


FIG. 4.

The light from the arc is caught and projected in a more or less parallel beam by a parabolic mirror. The parabolic mirror, however, is not a perfect projector, in that it cannot produce an absolutely paralled beam of light, because the source of light cannot be confined to a point. We have seen that the quantity of light grew with the size of the light-producing area in the crater of the positive carbon. Hence, as we desire greater illumination or power, we have to enlarge our carbon to support or provide this area. In a parabolic mirror a certain amount of dispersion will be caused by the

fact that the illumination area of the positive carbon is an area and not a point. This dispersion becomes greater as the ratio between area of illuminating spot and focal length of mirror becomes greater, hence, to secure a good beam for large powers, it is necessary to use a correspondingly large mirror. Thus in the 36-inch projector, of which the focal length is 15 inches and diameter of incandescent spot about $\frac{3}{4}$ inch, it is a simple matter of trigonometry to show that the minimum amount of dispersion possible is about $(\tan^{-1}\frac{\frac{3}{8}}{15})$ $= 1\frac{1}{2}$ degrees on each side of the axis of the beam. There is another source of slight error of concentration due to the fact that while the silvered back of a mirror may be correctly cut, the near surface, which is also a reflector, must be necessarily different, and while manufacturers cut the near face on a curve that tends to correct this error, there still remains considerable dispersion. There is also a loss of light in a glass mirror, due to the absorption of the light by the glass of the mirror, and this absorption is of no small magnitude. The amount of this loss of course depends on the thickness of the mirror, but for average mirrors it may be placed at about twenty per cent. Efforts have been made to produce a metal mirror and thus eliminate this double reflection and absorption, and such mirrors have been made. One of the metals used was an alloy known commercially as Monel metal, which has many qualities eminently fitting it for this use, but results seem to point to at least no increase in reflective efficiency and dispersion, and we are still confronted with the liability of a loss of polish and consequently efficiency by oxidation, a condition to which glass mirrors are not subject.

The largest source of loss of light is due to the large amount of light that never reaches the lens, and is consequently lost. First, the negative carbon prevents a considerable amount of light from reaching the mirror, and all efforts to locate the negative carbon more favorably have failed. In practical operation this loss is minimized by

maintaining the arc at as great a length as is compatible with steady operation. Secondly, considerations of expense of manufacture, strength and liability to fracture, and size and ease of handling, limit the amount of the paraboloid, which can be utilized for a reflector, and thus a certain quantity of light escapes beyond the limits of the mirror and is absorbed or reflected away by the sides of the searchlight barrel.

In endeavoring to secure a parallel beam it is only necessary to move the carbons, that is the lamp, back and forward in the axis of the lens until the beam becomes as nearly a pencil of rays as is possible. Best results are found when the ray is what is known as a concentrated beam, that is when the source of light is a very small distance outside the focus. With the source of light in this position the error of dispersion, mentioned above, is somewhat decreased. As a matter of fact, it is with this slightly concentrated beam that we approach nearest to a true parallel beam. The relation between the current used in the different sized searchlights manufactured by the General Electric Company and used by the Navy, and the dimensions of the carbons and lenses used in them, is shown in Figs. 5, 6 and 7.

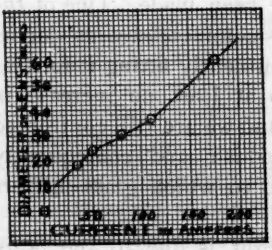


FIG. 5.

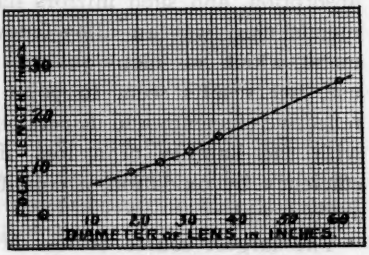


FIG. 6.

The following table gives the results from some German investigation, and may be used to exemplify several of the facts previously discussed. It is published in Foster's Electrical Engineer's Pocketbook. The true measure of a search-

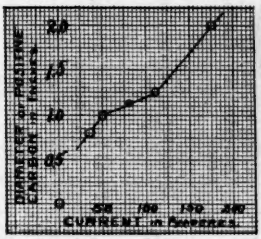


FIG. 7.

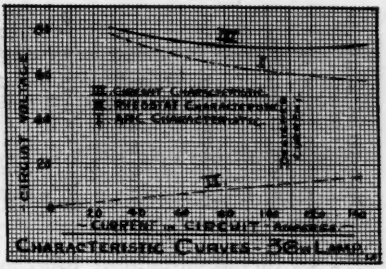


FIG. 9.

light's efficiency or excellence is to ascertain, if possible, what illumination it will produce at a given range. This is, however, a very difficult operation, as atmospheric conditions play such an important part in the final results. It is not at all difficult, however, to deduce accurate results as regards the relative efficiency of several lights, provided we base our arguments on proper foundations.

It is a matter of simple geometry to prove that, neglecting atmospheric absorption, light intensity varies as the square of the distance, and that fact may be accepted as axiomatic.

The light from the crater is gathered in by the mirror and projected in a cone-shaped beam. The apex of this cone is in the rear of the mirror and its distance from the mirror depends on the dispersion and diameter of the mirror.

For instance:

Let

D = Angle of dispersion;
d = Diameter of mirror, in feet;
d_1 = Diameter of crater, in feet;
f = Focal length of mirror, in feet;

then the location of this imaginary point is $\frac{d}{2} \cot \frac{D}{2}$ feet in rear of the mirror.

The magnifying or intensifying power of the mirror is measured by the distance that this point is in rear of the mirror, and hence as the intensity of light varies as the square of the distance, we may express this power by the ratio

Diameter of mirror, in inches.	Current, in ampères.	Volts across arc.	Watts in arc.	Hefner candles per watt.	Mean intensity, in Hefner candles, of light falling on mirror. Corrected for absorption.	Diameter of crater, in inches.	Focal length of mirror, in inches.	Angle of dispersion.
								Deg.min.
15.8	20	43.5	870	4.00	2,500	.365	7.4	2 58
15.8	25	44.0	1,100	4.60	3,600	.370	7.4	2 59
15.8	30	44.0	1,320	4.80	4,500	.374	8.2	2 43
18.4	20	43.5	870	4.00	2,500	.365	8.2	2 40
18.4	30	44.0	1,320	4.80	4,500	.374	8.2	2 43
18.4	40	45.0	1,800	5.14	6,660	.393	8.2	2 52
24.5	40	45.0	1,800	5.14	6,660	.393	10.2	2 18
24.5	50	46.0	2,300	5.35	8,820	.430	10.2	2 30
24.5	60	47.0	2,820	5.55	11,150	.470	10.2	2 47
30.6	60	47.0	2,820	5.55	11,150	.470	12.7	2 16
30.6	75	49.0	3,675	5.80	15,300	.563	12.7	2. 38
30.6	90	51.5	4,635	6.00	20,500	.657	12.7	3 06
36.7	60	47.0	2,820	5.55	11,150	.470	12.7	2 16
36.7	75	49.0	3,675	5.80	15,300	.563	15.5	2 08
36.7	90	51.5	4,635	6.00	20,500	.657	15.5	2 32
36.7	100	53.0	5,300	6.05	23,130	.690	15.5	2 43
36.7	125	55.5	6,938	6.23	29,880	.787	17.2	2 44
36.7	150	59.0	8,850	6.45	41,040	.906	17.2	3 08
45.0	150	60.0	9,000	6.50	41,750	.906	21.3	2 32
61.0	150	60.0	9,000	6.50	41,750	.906	26.6	2 02

$$\frac{\left(\frac{d}{2}\cot\frac{D}{2}\right)^2}{f^2}.$$

Let M = intensifying power of mirror,

then $$M = \frac{\frac{d^2}{4}\cot^2\frac{D}{2}}{f^2};$$

but $$\cot\frac{D}{2} = \frac{f}{\frac{d_1}{2}};$$

hence $$M = \frac{\frac{d^2}{4}\left(\frac{f}{\frac{d_1}{2}}\right)^2}{f^2} = \frac{4 d^2 f^2}{4 d_1^2 f^2} = \frac{d^2}{d_1^2},$$

and the intensity of the ray of light sent out by the mirror may be expressed as follows:

Let

I_m = mean intensity of light impinging on mirror;

I_p = intensity of projected beam;

then $$I_p = I_m \left(\frac{d^2}{d_1^2}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

This method is very generally used in comparing searchlights, but while it does express a very fair relation between searchlights, as far as their relation exists at the lamp, it fails to give a relation which will take in their action on a distant target. Foster uses this method of comparing searchlights in his Electrical Engineer's Pocket Book.

Let us try comparison in another way: The intensity of a beam or ray of light at any point is inversely proportional to the area illuminated, or, in other words, any ray or beam of light the product of intensity at any point with area illuminated at that point is, disregarding atmospheric absorption, a constant.

For instance:

Let R = Distance of a target, in feet, whose area is sufficient to catch the full illumination of the beam:

D = Angle of dispersion;

A_r = Area of target illuminated at range;

d = Diameter of mirror, in feet;

d_1 = Diameter of crater, in feet;

f = Focal length of mirror, in feet;

I_m = Average intensity of light falling on mirror;

Then $$A_r = \pi \left(R \tan \frac{D}{2} \times \frac{d}{2}\right)^2.$$

The area illuminated at the light is $\frac{\pi d^2}{4}$ and the total quantity of light leaving the mirror is $I_m \left(\frac{\pi d^2}{4}\right)$ square-foot candles.

Let I_r = Intensity of illumination at target.
Then (neglecting atmospheric absorption)

$$I_r \times \pi \left(R \tan \frac{D}{2} + \frac{d}{2}\right)^2 = I_m \times \frac{\pi d^2}{4}$$

or

$$I_r = \frac{I_m d^2}{4\left(R \tan \frac{D}{2} + \frac{d}{2}\right)^2};$$

but

$$\tan \frac{D}{2} = \frac{\frac{d_1}{2}}{f}.$$

Hence

$$I_r = \frac{I_m d^2}{4\left(R \frac{\frac{d_1}{2}}{f} + \frac{d}{2}\right)^2}, \quad \ldots\ldots\ldots \quad (2)$$

an expression in which all the factors are known, or may be ascertained, at the light.

Let us compare a few of the lights given in the table by these two methods. For instance, take two whose current and consequently intensity of illumination are the same, but whose focal length and diameter differ, and we have:

	No. 1.	No. 2.
Diameter of mirror, inches, . .	15.8	18.4
Focal length of mirror, inches,	7.4	8.2
Intensity of light leaving mirror, candles, ...	2,500.0	2,500.0
Diameter of crater, inch, . . .	.365	.365
Range, inches, ...	12,000.0	12,000.0
We find by equation No. 1 that intensity of projected beam is,	4,635,000.0	5,850,000.0
And by equation No. 2 that intensity of illumination on target is, ...	2.128	3.489

It is to be noted how both of these methods agree that No. 2 light is better than No. 1 light, but it is by the second method that a true comparison is possible.

Again, let us take two lights with the same mirror but using different currents, as follows:

	No. 3.	No. 4.
Diameter of mirror, inches, .	36.7	36.7
Focal length of mirror, inches,	17.2	17.2
Diameter of crater, inches, .	.780	.906
Intensity of light leaving mirror, inches, ...	29,880.0	41,040.0
Range, inches, ...	12,000.0	12,000.0
By equation No. 1: Intensity of projected beam, . . .	66,170,000.0	67,340,000.0
By equation No. 2: Intensity of illumination at target, in candles, ...	119.5	123.5

Increase of illumination in the lamp does not necessarily increase the projected illumination on the target, but may actually decrease it. The possibility of this happening is easy to see without mathematical demonstration, for if the angle of dispersion should increase so as to make the illumi-

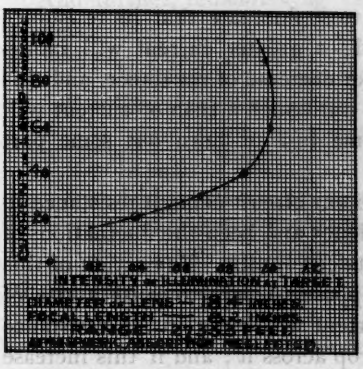


FIG. 8.

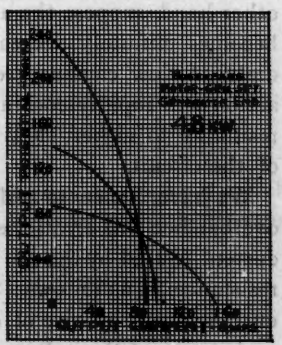


FIG. 12.

nated area enlarge more rapidly with increase of current than did the intensity of illumination in the lamp, then the intensity of illumination at the target must necessarily decrease. Thus we see that there is a limit to the intensity that may be projected on a target by a certain sized mirror.

In Fig. 8, the projected illumination for the 18-inch searchlight, is plotted from the data given in the table for a range of 2,733.3 feet.

POWER SUPPLY (CONSTANT POTENTIAL).

All the searchlights used by the Navy receive their current from constant-voltage mains, a situation necessary from present conditions but by no means ideal, for various reasons.

We have seen in Fig. 2 the relation existing between potential and current in the arc. It is evident therefrom that an arc cannot be connected directly to constant-potential mains. Suppose a lamp so connected and operating, and suppose by virtue of the the wasting away of the carbons that the arc length increases minutely. The resistance of the arc will consequently increase, which will, of course, cause a diminution in the current; this decrease of current will cause a further increase of resistance or higher voltage drop across the arc, and this changing will continue rapidly until the light goes out, because of a lack of voltage to maintain it. On the other hand, suppose the arc to so fluctuate that its resistance becomes minutely decreased; a greater current will immediately follow, causing greater decrease of resistance, and this action will rapidly continue until such a rush of current will result as to either blow some fuse or burn out some part of the circuit.

We have, hence, to add to our circuit enough resistance to overbalance this erratic tendency and keep the fluctuations of current caused by the arc between limits. The action of this resistance is as follows: Suppose the arc to cause a rise of current, then this rise of current will cause in the resistance an increase of the voltage drop across it; and if this increase of voltage drop in the resistance is sufficient, it will over-

balance the decrease of the voltage drop across the arc, caused by the increased current also, and thus choke back the current. On the other hand, suppose the arc to cause, by an increase of its resistance, a decrease of current; then this decrease of current will cause in the resistance a decrease of voltage drop, and if this decrease of voltage drop is sufficient, that is, if the amount of the resistance is sufficient, it will, by lowering the voltage drop of the circuit, permit additional current to flow.

It is a simple matter to find out how much resistance is necessary in series with the arc to produce this condition of stability, or, rather, the minimum voltage upon which the arc will operate at the designed current with a resistance in series with it.

For instance:

Let E = Potential drop of circuit, or drop, across arc and resistance (neglecting resistance of leads);
c = Current;
r = Resistance of rheostat, or resistance in series with arc;
e = Voltage drop across rheostat;

then $$e = cr.$$

And further, remembering the discussion of conditions in the arc,

Let e' = Voltage drop across arc;
e'' = Terminal voltage, or voltage consumed in maintaining the arc and heating the terminals;
l = Length of arc;
l' = Additional length, or abscissa of point from which characteristic curves appear to originate (for the carbon arc, $\frac{1}{3}$ inch);

then from the discussion in a previous chapter:

$$e' = e'' + \frac{k(l + l')}{c^{1/2}};$$

but by assumption $E = e + e'$;

hence $$E = cr + e' + \frac{k(l+l')}{c^{1/a}} \quad . \quad . \quad . \quad (1)$$

Now it must be true that when E is a minimum, we have the minimum amount of resistance in series with the arc, and E is a minimum

when $$\frac{dE}{dc} = 0;$$

or, differentiating equation No. 1, we have:

$$\frac{dE}{dc} = r + k(l+l')\left(-\frac{1}{a}\right)\left(\frac{1}{c^{1+1/a}}\right);$$

or, when E is a minimum,

$$r + k(l+l')\left(-\frac{1}{a}\right)\left(\frac{1}{c^{1+1/a}}\right) = 0;$$

but $$r = \frac{e}{c}.$$

Hence we have $$\frac{e}{c} - \frac{1}{a}\left\{\frac{k(l+l')}{c^{1/a}}\right\}\frac{1}{c} = 0;$$

but $$\frac{k(l+l')}{c^{1/a}} = e' - e'';$$

hence $$\frac{e}{c} - \frac{1}{a}(e' - e'')\frac{1}{c} = 0;$$

and eliminating c

$$e - \frac{1}{a}(e' - e'') = 0;$$

but $$E = e + e';$$

hence $$E - e' - \frac{1}{a}(e' - e'') = 0;$$

therefore the minimum voltage which can be utilized to supply an arc is

$$E = e' + \frac{e'}{a} - \frac{e''}{a},$$

or $$E = e'\left(1 + \frac{1}{a}\right) - \frac{e''}{a}.$$

To exemplify this, our 36-inch searchlight operates with 110 ampères at 60 volts, hence we will have to use a potential in our supply system of at least

$$60\left(1+\frac{1}{a}\right)-\frac{39}{a}\text{ volts.}$$

From reference back, we see that a is approximately 2, hence we have

$$E=\frac{60\times 3}{2}-\frac{39}{2}=71\text{ volts.}$$

We may proceed as follows to find the resistance necessary:

Let c = Designed current;

e' = Voltage drop across arc with that current;

E = Minimum voltage allowed;

r = Resistance of rheostat.

then $$r=\frac{E-e'}{c}.$$

These results may be summarized graphically. In Fig. 9, curve No. I shows the characteristic curve of the 36-inch searchlight when operating with 110 ampères and 60 volts across the arc. Curve II is the voltage drop across the resistance:

$$\frac{E-e'}{c}=\frac{71-60}{110}=\frac{11}{110}=\frac{1}{10}\text{ ohms,}$$

while curve III represents the characteristic of the circuit. Here we see that with the designed current our characteristic is horizontal, and the slightest variation in voltage of our arc or circuit will cause violent surges of current, a condition of the utmost instability. Hence we may call this point our "instability point." At the same time, however, our circuit characteristic has an upward tendency on each side of the operating point (110 ampères), or, in other words, will operate on an absolutely constant potential circuit.

It is evident from this that to get proper stability we will have to increase the resistance of our rheostat.

This instability point is at a voltage, as we have seen, of

about 50 per cent. of the arc *stream* volts over the *total arc* volts, but in general lighting practice, to get reasonable steadiness of current, a voltage of about 75 to 100 per cent. of the arc stream volts over the total arc volts is used. Thus on a 60-volt carbon arc about 76 to 81 volts would be maintained in the lighting circuit. This is not carried any higher than necessary, however, for in commercial practice power wasted in rheostats is paid for by the consumer, and the cost of running must be kept as low as possible. In the Navy our voltage is now 125 volts, so that we are well above the limit.

Let us see how the curve of our 36-inch light looks. We have to begin with circuit at 125 volts, and as this light is designed to operate at 110 ampères to give the proper illumination, and with that current consume 60 volts in the arc, we must insert in series with the arc a resistance of $\left(\frac{125-60}{110}\right) = \frac{13}{22}$ ohms. The voltage drop across the resistance is plotted as curve I in Fig. 10, the arc characteristic plotted as curve II, and the circuit characteristic as curve III. Here (Fig. 10) it is seen that the instability point has traveled a considerable distance to the left, or well below where our arc is operating, and it is very evident that the farther we can make this point be from our operating point the more reliable is our light. It is also evident that this can be done by increasing the voltage of our supply mains and the corresponding series resistance.

The desirability of securing this additional stability is of course presumed, for, aside from all question of electrical stability, it is axiomatic, almost, that we desire *light* stability, or, in other words, a field or beam of light of as nearly constant intensity of illumination as possible. A flickering light of a certain average intensity is evidently not as good as a constant light of the same intensity. It might be well to note at this point a certain factor effecting this flickering in the intensity of illumination, and that is the "flame" of the arc. While it is true that practically all of the light given off by the arc is due to the incandescent tip, yet the flame must give off a little

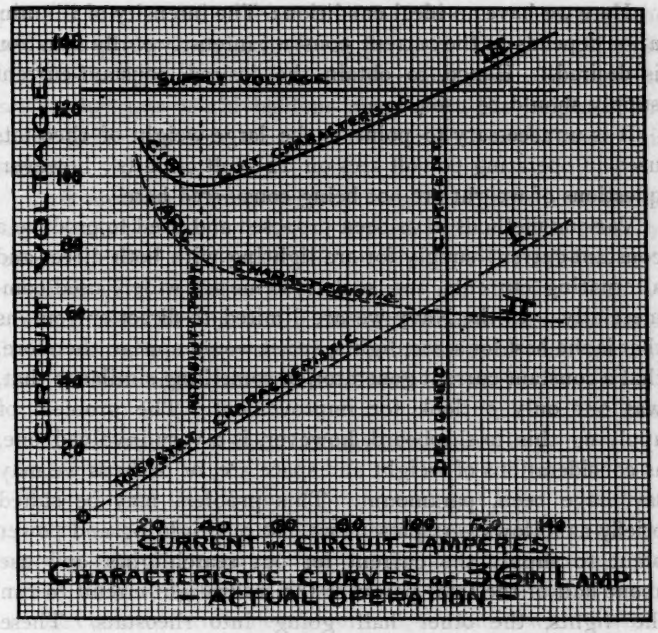


FIG. 10.

light also; and as the flame flickers, like a great many flames, we have, so to speak, a flickering fringe to the main light. However, this effect is not very great, especially as compared with the changes in intensity due to a change in current, a relative value of which may be seen by reference to the table shown previously.

To return to where we digressed. The statement that the arc will become more stable as the supply voltage and series resistance is increased may be stated another way, thus: Suppose that our voltage and resistance are so high that fluctuations of voltage drop in the arc are absolutely inconsequent as regards their effect on the current, then the current will be practically constant, and the arc absolutely stable or steady.

Here we have an ideal condition: The intensity of illumination depends on the current, constant intensity of illumination is desired. Hence, to obtain the desired, constant-current supply should be used.

It is unnecessary to point to the large weight of rheostats used in operating 60-volt arcs on 125-volt circuits; however, questions of weight are not being considered here.

Various methods have been proposed and used to produce a constant-current supply for arc lighting with both direct and alternating currents, and such systems are widely used commercially. In the Navy we are limited to direct current, as that is the best for searchlights, and it would appear, therefore, that a constant-current generator, or something similar to that, was our only outlook for improvement. The problem of applying this to shipboard, however, is a very involved one, as considerations of weight and space are, or perhaps we may say, have been, paramount. This problem may be stated briefly as follows: At present we use our lighting and power plant to supply the current for our searchlights, and use about half of the total power of the searchlight circuit to run the lights, the other half going into rheostats. These rheostats occupy space, have considerable weight and liberate a large quantity of heat.

To substitute constant-current supply we may do one of two things: first, substitute one constant-current generator for one of the regular constant-potential generators and use the searchlights of the ship in series with each other (an almost universal condition in city arc lighting); or, second, add to the regular electrical outfit, as at present installed, a motor-generator set for each light. With the first method a rheostat or dead-load resistance, capable of absorbing as much power as a light, would have to be installed for each lamp, so that should that lamp become short-circuited, destroyed, or otherwise thrown out of the circuit, the resistance could be substituted automatically, and the total load on the generator maintained practically constant. The weight of this outfit would, roughly speaking, be about the same as the

present outfit. The second method, however, entailing the addition of a motor-generator set for each light, would raise the total weight of searchlight installation; for, although the series rheostats would be done away with, the weight of the motor-generator sets would considerably overbalance this saving.

This problem is unsolved, or it might perhaps be better to say its solution has not been pursued with enough effort or encouragement. Constant-current supply will, in the writer's opinion, give us better results in our searchlights than we are at present having, and if enough demand is created for it it will come, as with everything else, in spite of what we may now consider objections or restrictions.

POWER SUPPLY (CONSTANT CURRENT).

It is evident that if we supply an arc light from a constant-current source no series resistance will be necessary in the arc circuit. As was seen in Fig. 2, the arc characteristic was nearly horizontal, hence if we supply the arc from a source whose characteristic is nearly vertical, the limits within which the arc must keep are very small, and steady operation and light will result.

A shunt generator is said to have a drooping characteristic, that is, its voltage decreases with increase of load. A series generator has a rising characteristic, or its voltage increases with the load. When the two fields of a compound-wound generator are addative, or work together, then by proper proportion of the fields the characteristic curve may be made almost a straight line, a condition resulting in the "flat compound" machine for constant-potential work. On the other hand, if we make the fields oppose each other we may make the characteristic curve assume a drooping shape, and the proportion between the fields may be so fixed as to make this curve have, around the point at which we desire the generator to operate, a characteristic giving very small changes of current with large variations of voltage. This machine is

the "differential compound" for constant-current use. This differential compound was about the first type of machine designed for constant-current work, and is, of course, applicable to searchlight work.

The advantage of using some such current supply can be easily seen by reference to Fig. 2 and also to Fig 11. In Fig. 11 is shown the characteristic curve of the 36-inch lamp at present most generally used, and by a full line is shown the ideal characteristic for a current supply for this lamp. One must, of course, be at right angles with the other.

There are other methods of securing a current supply of this nature than the "differential compound." The Rosenberg generator was designed for this purpose. The general characteristics of this generator are shown in Fig. 12, and its

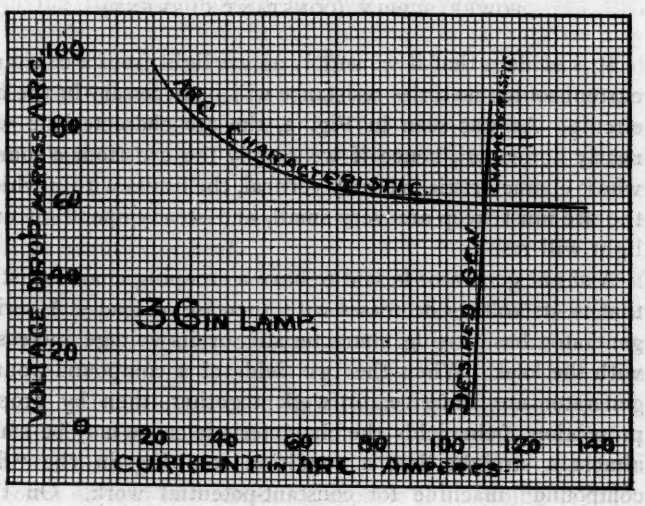


FIG. 11.

application to searchlight work is apparent. It should also be noted that various combinations assembled as "balancer sets" can be made to give similar characteristics.

It will thus be seen that constant-current supply is not very much of a problem.

We have seen in the early part of this paper the many difficulties to be overcome in producing a good searchlight and the many influences affecting the actual illumination on the target, and every point almost seems to hinge around current regulation. We are all familiar with the many difficulties at present experienced in searchlight operation and the great importance of getting as good a searchlight as possible. Our lamps, projectors and distant control are today at a very high state of efficiency. Let us hope that advance may now be made by installing constant-current supply for our lamps.

In the writer's opinion such a step is not only desirable but possible, and if obtained would materially assist and contribute to the great advance in general battle efficiency, which our Navy is striving for and gradually obtaining.

CARBONS.

The cross-sectional area of the carbons is governed by several general considerations, but it is by no means limited to certain exact dimensions. The negative carbon should be as small as possible in order that the useful light from the positive carbon intercepted by it will be a minimum. The positive carbon should be large enough to a little more than totally contain the incandescent spot caused by the designed current. Their sizes should also be so proportioned that each will burn at the same rate, and thus preserve the crater in the focus of the lens.

The sizes of carbons used in the various searchlights of the Navy are as follows:

Projector.	Diameter of negative.	Diameter of positive.
18-inch.	$\frac{5}{8}$-inch (solid).	$1\frac{3}{16}$-inch (cored).
24-inch.	$\frac{3}{4}$-inch (cored).	1-inch (cored).
30-inch.	$\frac{7}{8}$-inch (cored).	$1\frac{1}{8}$-inch cored).
36-inch.	1-inch (cored).	$1\frac{1}{4}$-inch (cored).
60-inch.	$1\frac{3}{8}$-inch (cored).	2-inch (cored).

Searchlight carbons are cored with a stick of soft carbon. This tends to center the arc, as, because of the softer nature of the core, the arc is supposed to naturally seek its locality.

The voltage drop across an arc is for the same reason less when the carbons are cored than when solid; or for the same voltage drop across an arc the cored carbons will have a shorter arc length than the solid ones. Carbons should be of uniform quality, so as to facilitate as far as possible uniform conditions in the arc, and thus assist in the maintenance of a uniform current. It is extremely difficult, however, to obtain this condition, and, although carbon manufacturers produce enormous quantities of carbons and carry on extensive research and experiment, the carbons of today are far from fulfilling the conditions. The resistance of the carbon depends largely on the temperature and time of baking in manufacture, and as the result appears to be extremely sensitive to variations in these conditions, it has proven almost impossible to obtain uniform results. For this reason the test of a searchlight lamp reduces itself almost to a test of the particular carbons in use at the time. While good results with searchlights depend largely on the carbons employed, it is the writer's belief, however, that many troubles ordinarily blamed on the carbons could, with a little further investigation, be located elsewhere and perhaps corrected. For instance, the effect of wind or small air currents on the arc is, by changing or influencing the position of the arc stream, responsible for material fluctuations in the current and resultant changes in the illumination; and many such fluctuations are blamed on the carbons.

When the voltage drop across the arc, using the designed current, gets below a certain point, the arc emits a violent hissing, and the arc becomes erratic in its action. This point is called the "hissing point," and in testing carbons for a lamp this point must be below, by several volts, the voltage at which the arc is designed to operate.

When the voltage drop across the arc, using the designed current, gets above a certain point, that is, when the arc is

too long, the arc will begin to jump and sputter, and as the voltage is increased the arc will finally sing and flame at a great rate. These points are called the "jumping point" and "flaming point."

Thus, in choosing carbons, when the arc is about the right length and the current the designed current, the arc should operate at a voltage above the hissing point and below the jumping point of the carbons.

The life of the carbons is most easily found by burning the carbons a definite period of time and noting their weights before and after burning.

NOTES ON THE OPERATION OF SEARCHLIGHTS.

The following notes are by no means directions for operating, but merely a few observations, some of which may not be generally known.

In the first place, great care should be taken to see that the mirror and front glass are absolutely clean. The mirror alone absorbs about 20 to 25 per cent. of the light thrown upon it, and the front glass absorbs perhaps one-half that amount, or about 10 to 15 per cent. of the light reflected through it, and the addition of a light film of dust to either or both of these glasses will materially increase this loss. The best way to see that the glasses are clean is to observe them after starting up the lamp, as any dust which may have been invisible before starting is thrown into relief on the surfaces of the glasses by the light reflected or absorbed by it. A mirror or front glass thought to be clean when viewed in sunlight is often observed to be covered with a light film of dust when the light has been started.

The present type of lamp for the 36-inch projector is a double-feed lamp; that is, the carbons are either separated from or advanced toward each other by the feeding mechanism; and, as each of these functions is automatically controlled, the lamp gives very good results. It is not a bad idea, however, to check up the operation of this mechanism

by the use of the voltmeter and ammeter at the lamp. The lamp should operate at the designed arc voltage, and this is obtained by the proper adjustment of the little steel tension spring fitted in plain sight on the side of the lamp. This adjustment is made with a screw driver, but there should be no reason to change its adjustment unless someone has been tinkering with it, for it is most carefully adjusted by an expert at the factory before being shipped.

When beginning with a new set of carbons care should be taken to see that the carbons are in exact alignment, although the negative should be just a little lower than the positive. This difference in level is necessary because of the upward deflection of the arc stream due to the ascending air current caused by the heat of the arc, but it should be very small, and care should be taken to see that the positive is kept in its correct position so as not to disturb its location at the focus. It has been found also that a good arc can be more easily obtained on starting by sharpening the negative carbon in a lathe or grinder to an angle of about 15 degrees, or about the same as a good pencil point, and then blunting the point a little. The positive carbons, as supplied, are ready for use. Should old carbons be used, it would be a good plan to break off their tips and bring them in a lathe to the condition mentioned above.

If the arc stream does not center in the core of the positive carbon that carbon will almost certainly crack or break off in chips, and if the crater gets in very bad shape new carbons should at once be put in the lamp, if good results are desired. Under the best management, however, bad carbons will be found, and if after 10 minutes' operation, with good current regulation, they fail to settle down to steady burning, it is best to shut down immediately and substitute another pair.

It is very difficult for the attendant at the lamp to focus the beam properly, and he should be assisted if possible by some one as far away from the lamp as possible.

While the intensity of the light of the searchlight beam is almost the same over the whole illumination area, best results

seem to be obtained when that side of the beam of light nearest the observers or gun pointers is used to illuminate the target, the reason for this probably being that when the near edge of the beam is used the observer does not look through very much of the light, and hence gets a more clearly defined reflection in his eye. Sometimes, however, the intensity of the beam at the target may vary somewhat, due to the irregular burning of the carbons, and, as this can be very easily discovered by a careful observer, better illumination might sometimes result by shifting lights so as to make this bright part of the beam be in the near side of the beam for some other observer.

Best results of observation are unquestionably obtained when the observer is as far away from light as possible; the reason for our distant-control apparatus, and an argument for using the ends of the ship for locations for the searchlights.

Better illumination, because of steadier operation, will unquestionably result if the projectors are protected from as much wind or air eddies as possible, and the use of an old awning or blanket might, if properly placed, add materially to the steadiness of the light.

In conclusion, it may be stated that best results will undoubtedly be obtained when the lamp is run with the designed voltage and ampèrage. It is, of course, true that increase of current gives greater intensity of illumination in the arc; but it is very doubtful whether this increase of illumination is communicated to the target, for reasons explained previously. Each type and size of projector is very carefully designed, and the current assigned is probably the best. In addition, an increase in current will give a decrease of voltage drop in the arc, and the whole adjustment of the feeding mechanism will be disturbed. Therefore, in using the lights as furnished the designed conditions should be adhered to, good operation and light being obtained by carefully following the well-known laws and directions and endeavoring to get the best set, or a good set, of carbons.

NOTE.—The above is a thesis written by the author while at the Schenectady Works of the General Electric Company as a member of the post-graduate course in ordnance in 1910.

The following books have been consulted, and quoted from where noted:

Artillery Notes, No. 31.—Searchlights. By First Lieut. Lee Hagood, U. S. A., retired.

Electrical Engineer's Pocket Book.—Edition of 1908. Foster.

Radiation, Light and Illumination. By C. P. Steinmetz.

Assistance was kindly lent by:

Lieut. Comdr. L. McNamee, U. S. N., Inspector of Equipment, U. S. N., General Electric Co., Schenectady, N. Y.

Mr. J. L. Hall, Searchlight Engineer, General Electric Co.

Mr. A. Holt, Searchlight Operator and Tester, General Electric Co.

DEVELOPMENT OF THE MODERN GAS ENGINE.

By Commander J. Edward Palmer, U. S. Navy (Retired), Member.

INTRODUCTORY.

The operation of the modern gas engine may reasonably be expected to be eventually made nearly as reliable as that of the operation of the steam engine, provided continuous thoughtful consideration is given to the design, the construction and the supervision of all features of development of the first-named type of prime mover. In this monograph the general term gas engine is intended to include all appliances in which power is generated by explosive rather than by continuous-pressure action. This belief is founded upon the fact that there are now thousands of thoughtful and able designers at work upon giving to the world an improved gas engine, and as the result of such continuous efforts the appliance ought to develop into a more reliable and efficient machine, as well as one whose first cost would be very materially reduced from the price now charged for such construction.

This statement may appear surprising to many people, because in their own experience they have probably observed that the gas engine can be thrown out of commission from comparatively small troubles. The impairments of the gas engine likewise often involve excessive expense and time in overcoming such defects, due to the fact that comparatively few people have even a fair knowledge of the salient principles governing the design and operation of such motors.

The maintenance and operation of the steam engine is so familiar to tens of thousands of people that the ordinary impairment of such an engine can be quickly overcome even by those who have had but comparatively little engineering

training and experience. The steam engine in practical use, therefore, may be regarded as subtantially a reliable appliance for maritime and industrial needs, and it will not be many decades before the gas engine may be a formidable rival to the steam engine for carrying on special activities.

Reliability of Action of the Gas Engine.—In order to show the conditions requisite for the reliable operation of the gas engine it only ought to be necessary to tell in a very general way of those features that are of controlling importance in the operation of such type of machinery and of the ordinary impairments that are likely to take place. Under certain conditions the gas engine even now is a reliable appliance, and this statement may be attested by the fact that tens of thousands of automobiles are operated by persons who are not acquainted even with the elements of the mechanical principles of design that enter into the consideration of such machinery, nor even of some of the precautions that should be exercised in its operation. The machinery of automobiles, however, is exceedingly well built, efficiently assembled, thoroughly tested, carefully protected and installed in a manner that does not invite the tinkering of those who are unfamiliar with the principles of its operation.

The Development of the Gas Engine for Maritime and Naval Purposes.—The maritime and Naval interests of the world should have special interest in the development of the gas engine, by reason of the fact that the successful installation of such construction would minimize the great waste of heat that now exists in the burning of coal or oil fuel in the ordinary boiler. With the development of the gasoline engine there could be effected in marine craft considerable saving by cutting down the cargo space for fuel, as well as the fireroom complement of such vessels, thereby permitting valuable space to be used for other purposes. Whether measured from a financial or efficiency standpoint, the successful development of the gas engine is earnestly desired by all engineers.

In all probability the most enduring success will be obtained in the naval development of the gasoline engine if the Navy

Department will first commence experimenting with small appliances possessing a large factor of safety rather than by first attempting to develop gasoline machinery of extensive horsepower. There will be no enduring success obtained until the interest of the engine-room and fireroom force can first be aroused, for by experimenting along such lines most lasting results may be looked for. Practical difficulties that will be encountered as regards the operation of gasoline engines will be more fully known to the designers when investigation and research work is conducted with several small motors instead of with a comparatively few large-sized ones.

The Existing Detailed Features of Gas Engines.—Probably the best way of noting wherever particular advance in the improvement of the gas engine can be made, as well as in showing how readily such machinery can be efficiently and reliably operated by those having even a cursory knowledge of the principles of such mechanism, would be to tell of the essential features of such appliances, together with some of the difficulties that are encounted in their operation.

Valve Gear.—The simplest and most reliable design of valve gear now installed on a gas engine is that where the cam shaft is operated by two gear wheels from the crank shaft, with the valves either directly over the cam shaft and lifted by push rods, or with the valves installed in the upper part of the cylinders and operated by means of working beams from the push rods.

Oiling System.—In general, the most efficient oiling system so far devised is the combination of forced feed and splash. The oil reservoir in this design is installed in the bottom of the crank case. The oil is forced through the system, by an oil pump, to each of the main crank-shaft bearings, and then finds its way into small curved suspended oil troughs placed under each connecting-rod end. These troughs are shaped like an arc of a circle, the center of which is the center of the crank shaft, thereby permitting (with the rolling of the boat, in case of launches,) the connecting-rod ends to dip the same depth into the oil. The sides of the troughs are arranged so

as to give the best depth of oil. The oil is spread through the crank case to the cylinders, and finds its way back again into the reservoir at the bottom of the case, and can thus be used over and over again.

Carburetor.—The carburetor should be of the simplest form. There should be no springs or complicated mechanism to get out of order easily. It should have only a float, spraying nozzle, throttle valve, extra air valve to operate when throttle has opened a certain distance, and a gasoline-controlling needle valve between the float chamber and spraying nozzle. This valve is most important; it is used to regulate the supply of gasoline for changes in temperature, atmosphere and speed, and must be arranged to be easily operated. If operated properly it keeps the explosive mixtures of the proper proportions, which economizes fuel and prevents excessive formation of carbon in the cylinders.

The air-intake pipe should be arranged to take hot air from around the exhaust pipe, and a strainer should be placed on the gasoline supply pipe to collect all dirt, dust, etc. With this style of carburetor there should never be any carburetor troubles.

Magneto.—The modern high-grade magneto is a very reliable appliance. The magnetos on the busses in London run for more than 30,000 miles without any attention except using a few drops of oil every 500 or 1,000 miles and keeping them clean and free from dirt, dust, oil and water.

Too much stress cannot be given to the necessity of fitting the magneto with a cover which will protect it from all oil, water and dirt.

On a small engine which can easily be cranked by hand, it is suggested to do away with all batteries and dual ignition systems, and use only a high-tension magneto with a fixed spark advance of a well-known reliable make. Add to this mica spark plugs and a cut-out switch, and we have all that is necessary for a perfectly reliable system of the simplest form.

Fixed Spark.—The fixed spark is, of course, a compromise, and does not give the greatest economy at all speeds. On a

small launch engine the difference is slight, but the advantage gained in simplicity and ease of operation more than outweighs the small difference in economy. Considering likewise the hard usage launch engines receive, and as they are often operated by inefficient and careless men, the fixed spark is considered the best all around arrangement.

The intensity of the spark depends on the speed of the engine, and this to some extent makes up for the doing away with the changing of the spark advance. At low speeds when the intensity of the spark is less, the ignition and explosion of the charge is slower; and with greater spark intensity at high speeds, the ignition is faster. Thus with a fixed spark we get the same effect, but not in quite so marked a degree as when altering the advance.

The great majority of failures and troubles of the gasoline motor are traceable to the unreliability of the batteries, whether either of the dry-cell or storage batteries. All types of batteries are continually giving out or growing weak without warning, whether in use or standing idle, so that constant care and watching are necessary to keep them in efficient condition.

It is often difficult to obtain fresh dry cells as well as to maintain storage batteries properly charged, particularly on foreign stations and in out-of-the-way places.

As long as batteries are used there will arise complications as regards spark coils, multiplicity of wires, timers, etc., all of which are liable to get our of order and cause an endless amount of trouble.

By adopting the high-grade fixed-spark magneto we at once eliminate the above difficulties and obtain an ignition system which is at once simple and reliable. Such a magneto will run for years with no repairs, if properly cared for. The engine will be found easier to start, and we have a spark of highest intensity at the instant the charge is fired.

In the case of a changeable-spark magneto the advance is altered by the operator at will, or by an automatic governor attached to the magneto. It is practically impossible for the

operator to keep the changeable spark at the proper point for all conditions, so that, when using a changeable spark, it is really a matter of guess-work. It is claimed that the governor efficiently subserves this purpose; but, even if it does, which is not at all certain, the extra complications and liability to derangement more than offset the small amount of economy gained; consequently the fixed spark is by far the best for small launch engines.

As there may be some members of the Society who have not had practical experience in operating the "fixed spark" it may be advisable to briefly explain its action.

In the operation of the gasoline engine the compressed charge is fired by a "spark" just before the piston reaches the top of the stroke, and at a point that will allow the charge to become fully ignited, so that the full force of the explosion will be given just as the piston starts down on its power stroke. This is necessary because it requires time for the charge to become fully ignited. The time required to affect complete ignition depends on the size of the cylinders, the compression, the temperature of the charge and the intensity of the spark.

The point at which the spark fires the charge is called the "advance," and this advance should be changed for different speeds. When batteries are used the intensity of the spark remains the same no matter what the speed of the engine may be, consequently it is absolutely necessary that only inappreciable and even zero advance be given when starting, or else the motor would turn backward and thus cause a "kick back." As the speed of the engine increased the advance must be correspondingly increased in order to maintain the efficiency of engine by causing the charge to be fully ignited, as shown above, when the piston just begins its power stroke.

There is therefore nothing to guide the operator in changing the spark advance, except his judgment as to whether the engine is running properly or not.

When a fixed-spark magneto is used the best advance at which to set the spark must be determined by trial, and once the magneto coupling is clamped in position it should not be

altered. It will thus be seen the fixed-spark device entirely eliminates the personal equations of the operator in altering the advance.

As it is explained above, the intensity of the spark produced by the magneto depends on the speed of the engine. When the engine is running slowly the intensity of the spark is less, and the charge is ignited slower, and thus the full force of the explosion is not accomplished until the piston about begins its power stroke. At high speeds the intensity of the spark is greater and, consequently, the ignition faster, so that again the explosive force is produced just about the period when the piston begins its power stroke.

Angle of Advance.—The best advance at which to set the magneto must depend on the style of engine and should be determined by trial. It must not be so great as to cause a "kick back" when cranking by hand or to knock when running at low speeds. Yet it should be as great as the engine will stand without causing any of these faults. Ordinarily the angle of advance will be from 5 degrees to 15 degrees ahead of the crank, depending on size and style of engine.

Spark Plug.—The mica spark plug is by far the most satisfactory plug and should be used in preference to the porcelain plugs. The porcelain plugs are liable to crack with the heat, thus causing the packing to loosen and likewise alter the gap between the electrodes. The mica plug has none of these objections and will run for years with only occasionally adjusting the gap between the electrodes.

PRECAUTIONS TO BE TAKEN IN THE CARE AND OPERATION OF ENGINES.

General Supervision.—The greatest cause of any unreliability which the gas engine of today may have is due to the want of proper care in operation. It is astonishing to see the great lack of knowledge and efficiency displayed by many who run and take care of these engines. It may be well to enumerate a few of the most important rules and suggestions to be followed, and if these are regularly attended to in the

operation of a well-designed and constructed engine, one may be confident that a most satisfactory and enduring machine will be found in this form of motor.

If the engine is constantly running a careful inspection should be made daily of all nuts, bolts and springs, and compression noted when cranking. All bearings should be oiled and grease cups given half a turn.

Spark plugs should be inspected about once each month, cleaned if necessary, and the distance between the points of the electrodes adjusted to about .5 millimeter. This distance depends on style of motor and compression, so that a fixed rule for all cannot be given. All electrical connections should be kept tight and free from dirt and oil.

The magneto should be oiled with two or three drops of best sewing-machine oil about once each week, but great care must be taken not to allow oil to get on the contact breaker or the points. This part of the magneto should be inspected each week when oiling up the instrument. The contact breaker should be carefully wiped with a clean, soft, thin cloth to make sure that it is clean and free from oil. A narrow strip of clean writing paper drawn between the points when they are pressed together will show if there is any oil on them.

If oil or dirt gets on the contact-breaker points the surfaces will not only become scored or uneven from being burned, but uneven firing will result. When this happens the points will have to be very carefully dressed up with a fine, thin file. However, if the points are kept perfectly clean this will not have to be done. The distance between the points must be adjusted to about .5 millimeter when open. This distance depends on make of magneto used.

Carburetion.—The majority of gas engines are operated with the mixture too rich. One reason for this is the mixture must be rich in order to start the engine, and then it is not changed after the engine is started. With a carburetor fitted with a gasoline-controlling needle valve, as above explained, the mixture can be adjusted at will while the engine is run-

ning. The mixture at all times should be kept just as lean as possible. This will economize fuel and prevent spark plugs and cylinders becoming foul. After the engine is running and has become well heated up, then close off the needle valve gradually, just as much as the engine will stand. One will be surprised to see with how little gasoline it can be operated. When the engine is slowed down or working to bells it must be opened a little, and, of course, when starting it must be well opened. A little practice in working this valve will soon show the operator just what the best adjustments are for different conditions.

Value of Graphite as Lubricant.—Graphite judiciously used in small quantities is an excellent lubricant when mixed with oil or grease. It is particularly good for the walls of the cylinders of the gas engines, as it is not affected by the high temperature produced by the combustion of the explosive mixtures. The oil burns up while the graphite remains. Graphite, however, has got in bad repute in many instances by too much of it being used, and the greatest of care should be taken to use it only in small quantities, as any considerable accumulation is liable to stop up oil holes and pipes and clog up exhaust passages.

Powdered flake graphite may be efficiently mixed with the grease and oil. About a quarter of a teaspoonful should be put into an oil-squirt can containing oil, and well shaken up before using, as the graphite is heavier than oil and settles to the bottom if not well mixed. In engines where the splash system only is used about an eighth of a teaspoonful of graphite may be put into the oil pocket under each cylinder once each month. When the crank case is cleaned out and new oil substituted twice this amount of graphite may be used in each pocket. Where there is a forced-feed return-oil system the use of graphite is not recommended, as it is liable to collect in the oil pipes and clog them up. A small quantity blown into the cylinders, mixed with the oil, or applied to the walls of the cylinders occasionally, will be found very beneficial.

Value of Acetone in the Eradication of Carbon from Com-

bustion Chambers and Exhaust Passages.—Despite the most intelligent care that may be exercised in regulating the consumption of gasoline and oil, carbon will form in the combustion chambers, on top of the pistons and in the exhaust passages of gas engines. One of the best ways of removing this carbon is to use some substance which will loosen the carbon from the containing wall. There are several such substances on the market, some of which are quite good. The main constituent of them all is "Acetone" (pyroacetic ether), which is, in itself probably the best carbon remover known. It is absolutely harmless, and, if properly used with intelligence, will satisfactorily accomplish the purpose intended.

Acetone is a commercial product and can be obtained at most all large or wholesale drug stores. Its use is recommended in preference to all other articles.

When injected into a warm cylinder acetone is converted into a gas, and if the cylinder is kept tightly closed for 10 to 12 hours it will separate the carbon from the walls of the cylinder. It does not dissolve the carbon, but will simply loosen it so that the carbon falls off from the cylinder walls and may be blown out through the exhaust.

About once each month or oftener the carbon that has accumulated should be removed. The directions for using acetone are as follows: Warm the engine by running it about ten minutes or so. The engine must not be too hot, yet it must be warm enough to convert the acetone into a gas. Arrange the valve mechanism so that all the valves are tightly closed and no gas will escape. If this cannot be done, then arrange matters so that half the cylinders will have their valves closed. This is an easy matter, as it is only necessary to crank the engine until one cylinder is on the compression stroke and another one is on the firing stroke; where there is a four-cylinder motor, two cylinders can be treated one day and the other two the next day.

Remove the spark plugs and inject into each cylinder, with an oil gun, from two to four ounces of acetone, being careful to replace the spark plugs at once before any of the gas escapes.

Let the engine stand overnight and start up in regular way next morning, and then the carbon can be nearly all blown out through the exhaust. A little study and practice is required with different types of engines, in order to determine the best temperature, the amount of acetone to use, and how often it must be used to produce the best results. It sometimes happens after using a substance like acetone that a little carbon will lodge on a valve seat and cause a cylinder to lose its compression. In this case simply grind in the valve with a little kerosene, and this will generally remove the loose carbon off the valve seat.

An engine must not be allowed to go too long a time without having the carbon removed, because when the carbon becomes very hard it is difficult to remove it except by scraping. However, if acetone is intelligently used good results are sure to follow, and one will be repaid for using it.

While the above directions for taking care of an engine may seem to some, at first sight, to be arduous, in reality they are not. If those who operate gas engines would get themselves into a regular routine of attending to these details they would soon become experts in detecting faults. The work required to be done in properly caring for a gas engine is so moderate and the results obtained so satisfactory that those exercising this care will be amply repaid for their labor and attention.

The Existing Inherent Weakness of Gas-Engine Design and Construction.—While there may be a sufficient reserve factor of safety established by designers of small gas and gasoline engines, there is no doubt but that the serious impairments which have occurred to both gas and gasoline machinery of extensive if not of moderate horsepower, is due to the inadequate factor of safety that has been employed in designing the various parts of heavy machinery of the explosive type.

The strain to which explosive engines are subjected may be likened to that of an appliance which is revolved by a series of rapid intermittent blows rather than by the comparatively

uniform pressure that exists in such a motor as the steam engine.

It is probably undeniable that, if the factor of safety of certain parts of explosive engines were doubled when designing such machinery (thereby permitting larger-sized shafts, heavier housings and thicker cylinders to be installed), the efficiency and endurance of such machinery would be greatly promoted.

The experience of all Navies in the operation and development of submarine boats bears testimony to the fact that a decidedly too small factor of safety is employed in the design of such machines. The shafts are probably too small in diameter to withstand the impulsive heavy shock to which they are subjected and the housings too light for the condition under which the engines are operated. The efficient operation of the submarines for protracted periods will probably never be brought about until the factor of safety of such machinery is increased and heavier engines thereby installed. The installation of considerable additional machinery weights can probably only be effected at the expense of other important features of construction. The general unsatisfactory endurance of such machinery, however, undoubtedly shows that the existing installations are too light for continuous work. Naval officials in particular should therefore give special consideration to the question as to whether the time is not opportune for providing a larger factor of safety for all integral parts of explosive engines that would be commensurate with the excessive and unusual character of stress to which the various parts of such machinery are subjected.

General Observations.—There is no mystery either about the design or operation of the modern gas engine that should ultimately prevent its more general adoption for both industrial and maritime purposes. The principal hindrance heretofore to its more extended use has been due to the fact that too many experts have been prone to regard this type of motor as an instrument of precision and as an appliance that required exceptional skill and intelligence in its design, manufacture

and operation. The development and more extended use of the gas engine will be effected if its salient principles are made more fully known to engineering students and intelligent mechanics rather than by depending entirely upon the research work and investigation of a comparatively few skilled designers and technical experts for further improvement and efficiency.

NOTES.

"THE SAVING OF HEAT UNITS IN MARINE MACHINERY."

DISCUSSION OF PAPER.

By Leo Loeb, M. E., Associate.

The paper of Lieutenant Commander Dinger in the August Journal under the above title considers in detail the design and operation of main and auxiliary machinery on board ship with a view of securing better economy. With respect to the section on Reheaters and Series Feed Heaters, the results of theoretical ecomony are greater than would be expected in a case where such a small part of the steam in its passage through the engine is diverted from its usual course of adiabatic expansion and used for reheating and feed heating. The figures on pages 384 to 388 have accordingly been checked, using Marks and Davis' Steam Tables, and assuming that each of the pressure conditions in the original examples was on the absolute scale.

The first example, in which dry saturated steam is expanded through a triple-expansion engine from 260 pounds absolute to 1.5 pounds absolute with receiver pressures of 110 and 25 pounds absolute, yields the following:

Initial pressure, pounds absolute	260
Terminal pressure, pounds absolute	1.5
Heat content of entering steam, B.t.u. per pound	1,202.0
Initial quality	1.000
Final quality	0.766
Heat content of exhaust steam, B.t.u. per pound	870.6
Heat abstracted, B.t.u. per pound	331.4

Assuming the moisture at the exhaust from each cylinder to be trapped from the receivers and used to heat feed water to 200 degrees F.,

Heat content of entering steam, B.t.u. per pound	1,202.0
Initial quality	1.000
Quality after expansion to 110 pounds absolute	0.937
Heat content after expansion to 110 pounds absolute	1,132.6
Heat extracted, B.t.u. per pound	69.4

6.3 per cent. moisture at 334.8 degrees F. is drawn off, and when utilized for feed heating to 200 degrees F. would yield in B.t.u. per pound,

$$.063 \times (305.5 - 167.9) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 8.7$$

The dry steam remaining, 93.7 per cent. of the original weight, is then expanded in the intermediate to 25 pounds absolute.

Heat content of entering steam, B.t.u. per pound	1,188.0
Quality after expansion	.912
Heat content after expansion, B.t.u. per pound	1,076.8
Heat extracted, B.t.u. per pound	111.2
Heat extracted per pound of original feed, $.937 \times 111.2$	104.2

8.8 per cent. moisture at 240.1 degrees is drawn off, and when utilized for feed heating at 200 degrees F. would yield, in B.t.u. per pound of original feed,

$$.088 \times (208.4 - 167.9) \times 937 \quad . \quad . \quad . \quad . \quad . \quad . \quad 3$$

The remaining dry steam is then expanded in the low-pressure cylinder to 1.5 pounds absolute.

Heat content of entering steam, B.t.u. per pound	1,160.4
Quality after expansion	0.873
Heat content after expansion, B.t.u. per pound	979.8
Heat extracted, B.t.u. per pound	180.6
Heat extracted, B.t.u. per pound of original feed, $.937 \times .912 \times 180.6$	154.2
Totals:	B.t.u.
High	69.4
Intermediate	104.2
Low	154.2
First receiver	8.7
Second receiver	3.3
Total	339.8
Direct expansion	331.4
Difference	8.4

For the second example, in which steam at 260 pounds absolute, superheated 75 degrees, is used in a triple-expansion engine with receiver pressure of 110 and 50 pounds absolute, and exhausted from the low-pressure cylinder at 15 pounds absolute for final utilization in an exhaust turbine to 1 pound absolute, the quantities are:

Initial pressure, pounds absolute	260.
Terminal pressure, pounds absolute	1.0
Initial quality superheat, degrees	75.
Heat content entering steam, B.t.u. per pound	1,250.7
Final quality	0.784
Heat content of exhaust steam, B.t.u. per pound	880.6
Heat abstracted B.t.u. per pound	370.1

Now, carrying the expansions by stages and considering the exhaust from the second receiver to be used for reheating the low-pressure exhaust and then for feed heating to 200 degrees F.:

Heat content of entering steam, B.t.u. per pound	1,250.7
Initial condition superheat, degrees	75.
Quality after expansion to 110 pounds absolute	.986
Quality after expansion to 50 pounds absolute	.939
Heat content after expansion, B.t.u. per pound	1,117.3
Heat extracted, B.t.u. per pound	133.4

6.1 per cent. moisture at 281 degrees is drawn off, and when utilized for reheating and feed heating at 200 degrees F. would yield, in B.t.u. per pound,

$.061 \times (250.1 - 167.9)$ 5.0

The remaining dry steam is then expanded in the low-pressure cylinder to 15 pounds absolute.

Heat content of entering steam, B.t.u. per pound	1,173.6
Quality after expansion	.933
Heat content after expansion, B.t.u. per pound	1,085.7
Heat extracted, B.t.u. per pound	87.9
Heat extracted per pound of original feed, $.939 \times 87.9$	82.5

Of the 5.0 B.t.u. rejected in water of condensation in the low-pressure receiver, 3.1 B.t.u. is utilized in reheating and 1.9 in feed heating.

Total heat of steam to low-pressure turbine after 3.1 B.t.u. reheating is

B.t.u. per pound	1,088.8
Quality after reheating	.936
Quality after expansion to 1.0 pound absolute	.830
Heat content after expansion, B.t.u. per pound	929.5
Heat extracted, B.t.u. per pound	159.3
Heat extracted, B.t.u. per pound of original feed .939 × 159.3	149.7
Totals:	B.t.u.
High and intermediate	133.4
Low	82.5
Turbine	149.7
Reheating	3.1
Feed heating	1.9
Total	370.6
Direct expansion	370.1
Difference	0.5

So that theoretically the gain is insignificant and is due to the conversion into feed heat of waste heat from the cylinders. Actually the gain is, as pointed out by Lieutenant Commander Dinger, much greater, because initial condensation accounts for a larger percentage of moisture than adiabatic expansion, and the removal of this water of condensation at each stage provides a source for greater reheating.

As an example of what may be accomplished by reheating there are available several reliable tests of stationary engines of smaller power than those found in marine practice.

A Rice and Sargeant engine, 20.03 inches and 40 inches × 42 inches, 120 r.p.m., tested by Prof. Jacobus, had reheater coils supplied with live steam as well as high and low cylinder-head jackets. The high-pressure clearance was 4.7 per cent. and the low-pressure clearance 7 per cent.

Results of tests at two loads are as follows:

	I.	II.
I.H.P.	1,004.3	853.3
Steam pressure, pounds absolute	162.8	164.7
Vacuum, pounds absolute	1.22	1.00
Quality of steam	.997	.997
Total steam per hour, including jacket and reheater steam, pounds	12,803.	10,520.
Jacket and reheater steam, pounds per hour	1,475.	1,042.
Steam per I.H.P. hour, pounds	12.75	12.33
Quality of steam at cut-off in the high	.886	.887
Theoretical thermal efficiency	28.1	28.7
Actual thermal efficiency	17.8	18.4
Per cent. ideal efficiency attained	63.3	63.9

On a similar engine of somewhat smaller dimensions, 16.07 inches and 28.03 inches by 42 inches, the performance with superheat was:

I.H.P.	420.4
Steam pressure, pounds absolute	157.0
Vacuum, pounds absolute	1.92
Superheat, degrees F.	374.5
Steam per I.H.P. hour	9.56
Theoretical thermal efficiency	28.2
Actual thermal efficiency	18.9
Per cent. ideal efficiency attained	67.2

This engine was equipped with Schmidt receivers, in which reheating was accomplished by a portion of the superheated steam going to the high-pressure cylinder.

The efficiencies referred to in Lieutenant Commander Dinger's paper are in most cases apparently the per cent. of ideal efficiency attained. His statement "it is not unusual to secure 80 to 85 per cent. efficiency in large reciprocating engines ashore. Eighty per cent. has been guaranteed for many years," must be taken to refer to mechanical efficiencies, since the numbers cited are somewhat larger than the best stationary practice. A summary of reliable data on the best performance of certain stationary generator engines is given in Table I. In calculating the theoretical thermal efficiency 90 per cent. is assumed for the combined engine and generator efficiency.

For the same class of service the high-pressure turbine at high speed, 750 r.p.m. to 3,000 r.p.m. has shown no higher ecomony, the most reliable figures for each of the several types being:

	Per cent. thermal efficiency attained.		
	Low speed, 1,000 r.p.m.		High speed, 1,000–3,000 r.p.m.
Curtis Parsons	67.0	to	71.8
Parsons	64.3	to	68.8
Curtis-Rateau	67.0	to	68.7
Zoelly	65.7	to	67.5
Rateau	...		66.1
Curtis	61.9	to	66.5

The Heaton Works of the C. A. Parsons and Co., Limited, have just completed for the Commonwealth Edison Company, Chicago, Ill., a 25,000-kilowatt set which mounts on one shaft a single-flow, parallel-type, high-pressure turbine, and a double-flow low-pressure turbine flexibly coupled to a three-phase, 25-cycle, 4,500-volt alternator. The speed is 750 r.p.m., and the guaranteed steam consumption with 200 pounds throttle pressure, 200 degrees superheat and one inch of mercury absolute back pressure is 11.25 pounds per kilowatt hour, with a penalty and bonus correction of 2,500 dollars per one-fifth pound variation from 11.25.

This guarantee, if accomplished, will result in an overall thermal efficiency of 72.5 per cent. of the ideal. Since the generator efficiency of so large a unit is undoubtedly as high as 96 per cent., the thermal efficiency of the turbine alone is 75.6 per cent. of the ideal, a result which is probably the very best obtainable from a typical Parsons design. Reduced to shaft-horsepower performance, the guaranteed economy is 8.09 pounds per hour as against a theoretical of 6.07, a figure not heretofore attained in marine practice.

The most notable betterment of plant economy produced by the addition of low-pressure turbines to compound reciprocating engines is that shown by the 59th Street Station of the Interborough Rapid Transit Company of New York. This station, with a capacity of 67,500 kilowatts generated with double compound Allis engines at 75 r.p.m., met the demand for increased power by installing a Curtis low-pressure turbine at the exhaust end of each of the 7,500-kilowatt engine units, and practically doubled the capacity of the plant with the only additional expense of the turbine and its generator, and of larger capacity in condenser and air pumps.

When the extension of this plant was considered, the engineers carefully investigated the possibility of increased economy from the following prime movers:

(1) Gas engines;
(2) Water-power development from upstate falls;
(3) High-pressure turbines;
(4) Combination low-pressure turbines with existing engines.

The first possibility was rejected because it was feared that at that stage (1910) of the development of the gas engine the plant could not meet the re-

quirement of a total interrupted service of less than ten minutes per annum, as well as involving 35 per cent. increased initial cost and four to nine times maintenance cost of a steam plant. The second was abandoned for similar reasons, arising, however, from distant control and high cost of double transmission line rather than unreliability, and, between the third and fourth, the latter was chosen because of better guarantee of economy and less original investment, this second item, however, being of scant importance where the operating expense is so large as compared with first cost.

The results obtained with one unit in the remodeled plant were so favorable that the other eight units were quickly converted. From a steam economy as shown by the last item of Table I, 17.82 pounds per kilowatt hour, the performance came to 13.19 pounds per kilowatt hour, measured at the switchboard. The details of the two tests are:

	Engine alone.	Engine and L.P. turbine.
Load, in kilowatts	5,496	11,240
Steam pressure, pounds	190.0	194.0
Quality of steam	Dry.	98.6° sup.
Vacuum, 29.92 inches barometer	25.02	28.73
Steam per kilowatt hour	17.82	13.19
Thermal efficiency, per cent	17.5	22.8
Theoretical thermal efficiency, per cent	24.0	28.0
Per cent. theoretical efficiency attained	72.9	81.5
Steam per I.H.P. hour (calculated)	12.78	9.45

It is apparent that some of the gain is due to the better vacuum and superheat, but it must be borne in mind that the engine is not able to utilize those advantages to the same extent as the turbine. The same care in the selection of units for marine installation should therefore result in a water rate of ten pounds per shaft horsepower.

A discussion of the economy of engines would be incomplete without some reference to the Una-flow steam engine, the recent development of Dr. J. Stumpf, of Berlin. This engine embodies some points of design which are distinct reversions from what had been considered best practice, in that the expansion is carried from throttle pressure to exhaust in one cylinder. Steam is admitted through poppet valves in the cylinder heads and exhausts through diamond-shaped ports at the center of the cylinder. The exhaust ports are uncovered by the piston, which has in this engine a length about equal to the stroke requiring a cylinder length of double the stroke. Compression is therefore fixed by the position of the exhaust ports, and compression pressure is carried to inlet steam pressure, so that the cylinder head and piston are heated to almost steam temperature before live steam is admitted. The basis of the claims for the economy of this engine are made upon the reduction of cylinder condensation, since live steam comes in contact with metal walls of its own temperature and the steam flow is from the head to the exhaust end, whence the name "una-flow." Beside the saving in steam accomplished by this engine, there is a reduction in the number of working parts—the entire number of parts for one engine being 33, as against about 120 for a triple-expansion engine of the same power—less weight per horsepower, which for naval work is in part counterbalanced by the disadvantage of greater head room for the long cylinder. To permit complete expansion in a single cylinder the cut-off for economical operation must be very early, amounting at normal full load to 12 per cent. The greatly increased power to be obtained by lengthening the cut-off is a factor of tactical value when a great amount of power is required at a time when economy is not paramount. Moreover, this engine develops the excess power without increasing the stress on any parts of the engine except those subjected to dynamic forces. No tests of the Una-flow engine in sizes suitable for marine purposes have been noted, but the results on a 17.5-inch $\times$ 23.5-inch, 180-r.p.m engine are interesting as indicating possibilities.

	I.	II.
Load, I.H.P	183.6	184.0
B.H.P	161.4	162.0
kilowatts	108.7	109.0
Steam pressure, pounds gage	139.7	138.4
Quality	306° sup.	Dry.
Vacuum, 29.92 inches barometer	27.92	27.82
R.p.m	176.5	178.0
Steam per I.H.P. hour	9.54	13.64
per B.H.P. hour	10.78	15.46
per kilowatt hour	16.39	23.21

Another engine of the same type, with cylinders 23 inches × 31 inches, showed a steam consumption of 8.82 pounds per I.H.P. hour with superheat of 258 degrees, but the possibility of water rates of 8.0 pounds to 9.0 pounds per I.H.P. are remote, except with extremely high superheat, in which case the saving is only nominal, for there must be a greater heat generation in the boiler.

Great saving of heat can be accomplished, as was pointed out, in the operation of auxiliaries. Three other points might be added as worthy of attention: the careful lagging of all high-pressure piping, particularly flanges and fittings, from which the radiation of heat is very rapid; prompt attention to all steam leaks, and great care in boiler-room wastes. A one-eighth inch opening in a line carrying steam at 200 pounds pressure will leak over 3,200 pounds of steam in twenty-four hours, the coal equivalent of which is 450 pounds. It would not require many weeping gaskets to produce an equal waste. Leaks in boiler casings are costly consumers of heat units, and the utmost care in eliminating them will be rewarded by enviable coal records.

TABLE I.—ECONOMY OF GENERATOR ENGINES.

Plant and type of engine.	Load, kw.	Steam pressure, lbs.	Superheat, degs. F.	Vacuum, 29.92 inches barometer.	Steam per kw. hour, pounds.	Thermal eff., per ct.	Theoretical thermal eff., per cent.	Per ct. eff. attained.
Berlin-Moabit	1,920	202.7	223	28.00	13.35	20.4	27.8	73.4
Luiessenstrasse	1,950	202.7	264	27.00	14.00	19.4	26.8	72.4
N. Y. Edison-Westinghouse	3,872	200.0	dry	27.17	16.78	18.3	25.8	70.9
Boston Edison-McIntosh	1,500	176.5	92	25.40	16.47	18.0	23.8	75.6
N. Y. 59th St.-Allis	5,496	190.0	dry	25.02	17.82	17.5	24.0	72.9

DIESEL-ENGINE CYLINDER DIMENSIONS.

As a result of the large amount of experimental work that has been carried out within the last few years by several famous continental firms, it is now possible to determine in a fairly definite way the cylinder dimensions of Diesel engines of the two and four-cycle types for marine purposes.

Although as a rule we can predict economies better in internal-com-

bustion engines than in steam engines, it is not safe to rely on calculation alone in power determinations, for we cannot get nearly the same power from an engine that theoretical considerations would lead us to expect. It is also questionable if it would be economical to use much higher mean pressures than we at present obtain, for the simple reason that high mean pressures generally mean high terminal pressures, and it is not economical to exhaust at a high terminal pressure. Until means are found of utilizing the toe of the diagram, it is not wise to attempt more than we now obtain. Higher mean pressures in the cylinder produce higher mean bearing pressures, and all bearing surfaces would have to be increased. We know that it is already bearing pressures, as much as anything else, that fix crankshaft and crosshead-pin dimensions. In naval work, of course, it might be more economical to design with a view to obtaining the highest mean pressures possible, because naval engines are as a rule only called upon to give out their maximum power for short periods.

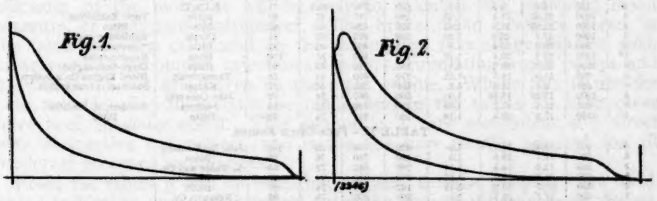
In this connection the suggestions of Professor Junkers, and those given in a paper before the Institution of Engineers and Shipbuilders in Scotland ("Engineering," May 3, 1912, page 605), seem worthy of attention. There it was proposed to work Diesel engines in an atmosphere much denser than that we breathe, such increased pressure being obtained in the manner explained in the paper just referred to. We have heard of the failure of some contracts for internal-combustion engines to work in high altitudes, due to the fact that the rarefied condition of the atmosphere was not taken into account in designing the engines, with the result that the plant failed to give out anything like the power expected.

It does not require any elaborate calculations to show that, with properly-designed apparatus, working under more than atmospheric pressure, an increase of 25 to 50 per cent. in the power over the maximum that could be obtained under normal conditions is possible. The arguments that might be used against this system are no more serious than those that could be used against forced draft, as we know it. In fact, if we consider the two-cycle system as the only system likely to be used in warship work, the arguments are much less cogent, for it is possible to obtain these overloads without the necessity of adopting closed engine rooms or subjecting the engine-room staff to anything but atmospheric pressure. As pointed out in the paper already referred to, it is only necessary to increase the pressure of the scavenging air by increasing the speed of the scavenging-air pumps, and at the same time to increase the back pressure on the exhaust side, so that the main engines would start compressing their charge at, say, 21 pounds per square inch absolute, or more, as against the customary 14.7 pounds to 16 pounds per square inch absolute. To increase the back pressure on the engine the simple water seal or throttle suggested would not cost much, and when the double doors, power-driven fans, sealed stokeholds, &c., of the usual steam installations are considered, the system, when applied to internal-combustion engines, is extremely simple and cheap.

With regard to engines for ordinary work, the economical amount of power that can be obtained from them is now well established, and it is quite a simple matter to determine the cylinder sizes of any new engines. There are, however, many considerations that vitally affect the power, efficiency and life of these engines that should be noted when deciding on the design and scavenging arrangements, especially of two-cycle cylinders. The crank-case compression Diesel engine is, for many reasons, not likely to appear. The chief one is that crank-case scavenging is notoriously inefficient, and the indicated mean pressure that could be supported in the cylinder would hardly exceed 50 pounds per square inch. With other systems of scavenging as much as 140 pounds per square inch indicated mean pressure has been obtained, so that this comparison is

rather striking. Also, since Diesel pressures are used, the crank-case compression engine would require to be designed to withstand those, and its weight per brake horsepower would therefore be quite inadmissible. Again, the economical piston speed for crank-case compression engines is about 700 feet per minute, whereas for other systems of scavenging the piston speed can be pushed up to 1,200 feet per minute economically. With crank-case compression the volumetric efficiency falls off so rapidly with the increase in speed that the power begins to fall away instead of to increase.

From another point of view this system of scavenging is bad. It means that half of the cylinder circumference only is available for the exhaust ports, while the other half is used for the scavenging ports. Hence the exhaust losses are much greater, because of the restricted area available for exhaust ports, and these ports require to be fairly long in comparison with the ports for other systems, a fact which makes the toe of the indicator diagram much longer, thus showing another loss. Annexed are two cards—one from a Diesel engine which introduced the scavenging air through valves in the cylinder cover (Fig. 1) and consequently had the whole circumference of the cylinder available for exhaust ports; and one (Fig. 2) from a port-scavenging engine. The difference in the toes is rather marked.



The chief drawback to scavenging through ports on one side of the cylinder and exhausting through others on the opposite side is that the bars on the scavenge side are much cooler than those on the exhaust side, and this causes unequal expansion, often resulting in cracked exhaust bars. Engines on this system, but having separate liners, are not so liable to suffer from this defect, as the liner seems to be able to accommodate itself to the unequal expansions much better than when cast integral with the cylinder. The crank-case compression type, as a rule, involves a baffle on the piston, and this gives a most awkward and inefficient shape to the combustion chamber, making it nearly impossible to obtain complete combustion with the little air that it is possible to get into the cylinder. The piston is also liable to crack on the crown, owing to its unsymmetrical shape, and it is necessary to give it more clearance fore and aft than athwartships to minimize any chances of seizing. It is also impossible to water-cool a part of the cylinder in way of the air ports, and to the touch, this part is always hotter than the water-cooled part.

One or two designs have appeared in which most of the scavenging air is introduced through valves in the cylinder cover and the remainder introduced through ports nearly opposite the exhaust ports. It is difficult to adduce any reasons for this practice, and it is possibly only done to obtain a patented design different from any on the market. This compound system complicates the scavenging air piping, and as the air-inlet ports are uncovered by means of a piston valve, it is necessary to add gear for reversing this valve. It undoubtedly costs more in air and power than would be necessary with a simple straightforward system, by which all the air was introduced through four valves placed in the cylinder cover. This

latter system is undoubtedly the best and most efficient. The exhaust products are swept out by a column of air with the minimum of intermixing, and the temperature changes all over the cylinder and piston are uniform. The whole circumference of the cylinder is available for exhaust ports, and these can be short so as to give the shortest toe possible to the indicator card.

The power of the engine being given, the first thing to determine is the proportions of the cylinders, and this can be done when a suitable stroke-bore ratio and piston speed have been selected. As a guide to designers, and as showing the practice of the most successful Diesel-engine builders, Tables I and II are given. These will guide the designer in his choice of a precedent. Table I refers to two-cycle engines, and Table II to four-cycle.

TABLE I.—TWO-CYCLE ENGINE.

No. of Cylinders.	B.H.P.	Cylinders. Dia.	Cylinders. Stroke.	Ratio: Stroke / Diameter	R.P.M.	Piston Speed.	Brake Mean Pressure.	Indicated Mean Pressure.	Name of Engine.	Remarks.
4	880	19.5	29.5	1.45	160	720	73	97	Sulzer	Monte Penedo
4	110	8.4	12.6	1.5	300	630	51	69	A. B. Diesels	Port scavenging
4	200	11.4	16.9	1.48	250	700	60	80	Ditto	Ditto
6	600	17.7	21.25	1.2	165	585	61	81	Ditto	Ditto
3*	1000	18.9	35.8	1.86	125	530	61	76	M.A.N.	Double acting
3†	6000	31.5	41.7	1.32	160	1110	76	95	Ditto	Ditto
6	150	6.9	9.86	1.35	550	790	46	68	Ditto	Single-acting
6‡	900	14.8	22.2	1.68	280	900	65	86	Ditto	Ditto
4	110	8.7	8.6	1.3	550	790	53.5	71	F.I.A.T.	
4	1000	21.65	31.5	1.45	150	790	47	62	Ditto	Turin Exhibition
4	1200	21.65	31.5	1.45	170	890	50	67	Ditto	Ditto
4	1000	17.7	23.0	1.29	250	915	61	81	Carels	Exhibition engine
4	800	20.0	30.0	1.5	115	690	61	81	Ditto	"Excelsior"
1*	1250	33 2	39.4	1.22	170	980	85	106	Ditto	Experimental
6	1500	20.0	30 2	7.51	120	790	67	90	Ditto	Cargo-boat engine
4	200	11.0	14 5	1.32	270	650	44	58	Thornycroft	Diesel Engine Co.'s design
6	300	9.8	11.8	1.2	450	885	58	77	Krupp	Submarine-boat engine
6	1000	17.25	17.25	1.0	300	882	54	72	John Cockerill	
3	650	15.4	17.7	1.15	180	530	71	96	Junkers	Builders, J. Prerichs
4	1100	17.3	20.5	1.18	150	510	74	96	Ditto	Ditto

TABLE II.—FOUR-CYCLE ENGINE.

6	300	9.45	14.17	1.5	320	780	80	100	Joh. Tecklenborg	
6	500	19.7	23.6	1.5	180	750	78	98	Ditto	
3	140	13.0	14.5	1.14	280	640	72	90	L. Noble and Co.	
6	800	14.7	16.9	1.36	310	670	74	92	Ditto	
4	350	17.7	20.0	1.13	190	630	74	92	Ditto	
4	500	17.7	20.7	1.5	200	690	75	93	Kolomna Co.	
6	900	17.7	18.0	1.02	250	750	72	90	Ditto	
3	200	15.7	19.7	1.25	200	655	80	86	Werkspoor	Sembilan
6	450	15.7	23.6	1.5	180	710	72	90	Ditto	Vulcanus
6	900	29.5	35.5	1.73	140	830	72	90	Ditto	
6	1100	23.6	29 6	1.68	140	980	61	76	Ditto	
4	300	13.0	13.0	1.0	400	885	86	107	Krupp	Submarine engine
6	430	13.0	14.8	1.14	400	980	70	87	Normand	Ditto
8‡	1550	20 6	23.7	1.38	140	670	90	102	Burmeister & Wain	Selandia

* Injection air-compressor separately driven. † Injection air-compressor and scavenging pumps separately driven.
‡ First and second stages of three-stage injection air-compressor separately driven.

Considering the two-cycle engine first, it will be noticed that for ordinary marine work the piston speed will be about 750 feet per minute, and the stroke-bore ratio may be anything from 1.25 to 1.9, with a distinct preference for 1.9. By adopting a fairly low piston speed and a large stroke-bore ratio, the endeavor is to keep down the revolutions as far as possible, not so much because of propeller efficiency, but because the engine will last much longer, wear-and-tear will be less, and there will be greater freedom from breakdown. For naval work the piston speed may be increased to 1,000 or 1,200 feet per minute with impunity. The stroke-bore ratio varies from 1.05 to 1.25, giving an average of 1.15. These high piston speeds and small stroke-bore ratios allow a light, low-lying engine to be made.

In marine calculations it is usual to refer to the indicated mean pressure and indicated horsepower. In oil-engine work it has always been the custom to deal with the brake or shaft horsepower, and when we come to apply this method to marine purposes there will be some difficulty. If the indicated horsepower be given, this must be converted into brake horsepower by assuming a suitable mechanical efficiency for the type of engine under consideration. This depends both on the size and type of engine,

and whether the scavenging and injection air pumps are driven wholly or in part by the main engine. For four-cycle engines up to 600 brake horsepower the mechanical efficiency may be taken at 80 per cent., and above this power at 85 per cent. In the case of the *Selandia's* engines the mechanical efficiency was returned at 90 per cent., but the first two stages of the three-stage injection air compressor were separately driven, and it was not stated if this was allowed for in the figure given. If not, then the figure given would be reduced by 3 or 4 per cent. For two-cycle engines, driving their own scavenging and injection-air pumps, the mechanical efficiency ranges from 75 to 80 per cent., the difference depending greatly on the system of scavenging adopted.

In calculating the size of the cylinder some designers allow so many cubic inches of piston displacement per brake horsepower, but such a figure conveys very little to the mind of the engineer who has been accustomed to dealing in pounds per square inch. Therefore, in the analysis of the engines listed in this article, it has been thought advisable to speak in pounds per square inch, and we have adopted the term brake mean pressure, which simply means the mean pressure calculated from the brake horsepower. Hence, if engines are designed by using such figures in calculating the sizes of the cylinders, it will be the shaft or brake horsepower that will be obtained. By taking into account the mechanical efficiency of the motor it will be easy to calculate the indicated mean pressure or indicated horsepower. The brake mean pressure given in the table has been calculated on the assumption that all auxiliaries, such as scavenging-air pumps, injection-air pumps, circulating-water pumps and gravity-oil pumps are driven by the main engine. Where this is not the case suitable allowances must be made, and in the tables all such cases have been specially noted. This method is a very convenient and direct way of treating the subject, and is the one now usually adopted for all moderate-powered installations.

From the tables it will be seen that no very definite pressures are used, every maker, as one would expect from the radical differences in design, getting different results. A knowledge of the constructional details of the various engines listed will enable one to trace why one engine is so much better than another in this respect. The tables contain a selection of practically all the large engines built or building, and in every case refers to Continental practice, since, so far, British practice is unfortunately non-existent.—"Engineering."

CORROSION OF CONDENSER TUBES.*

By GUY D. BENGOUGH, M.A., D.Sc. (Lecturer in Metallurgy in the University of Liverpool), and RICHARD M. JONES, M.Sc.

INTRODUCTION.

In a former report to the Corrosion Committee of this Institute one of the authors has drawn attention to the apparently erratic occurrence of corrosion in condensers, and the matter has been emphasized by numerous speakers both before and after the publication of that report. A number of explanations have been advanced to account for the phenomenon, but few of them are based upon rigid experimental tests. The recognized method of collecting information on corrosion hitherto has been to obtain

* Second report to the Corrosion Committee of the Institute of Metals.—Read before the Institute of Metals at Ghent, on August 28.

TABLE I.—COLLECTED INFORMATION FROM INQUIRY SCHEDULES.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
Business of Firm.	Length of Corroded Tube.	Normal Length of Service.	Percentage No. of Tubes in Tier Noted in Column I.	Length of Tube.	Position of Corrosion Along Length of Tube.	Position of Corroded Tubes in Condenser.	Maximum and Minimum Temperature of Water Leaving the Condenser.	Electric Lighting on Ship?	Protective Measures.	Period of Run.	Cause of Corrosion suggested by Firm.	Nature of Deterioration.
1. Shipping firm (to Tropics).	years 7½	years 15-20	6	ft. in. 12 9	Middle and inlet end	Top part of tubes	deg. Fah. 110 to 116	Yes. S.*	Iron slabs	12 days	Tubes "not new made of the same clean alloy as formerly"	Dezincification.
2. Same as (1). Another ship.	15	15-20	10	13 9	—	—	110 „ 116	Yes. S.	Do.	18 days	—	Thinning of inlets and plating.
3. Shipping firm (to Tropics).	4-7½	7-10	1.6	13 9	Inlet end	—	70 „ 110	Yes. D.	None	—	Bad material used for tubes	Dezincification and thinning.
4. Shipping firm (Cross Channel).	17	17	8.6	13 9	Each end of tube	Top part of tubes	95 „ 110	Yes. D.	Do.	22 hours	Corrosion due to packing which confined of tubes. Deposits on tubes	Thinning of tubes at ends and pitting.
5. Shipping firm (general trade).	8	7	—	13 1	Whole length of tube in pits	Top part	About 110	No.	Carbonate of soda put in doses of 1 to 2 ozs. per gallon	Various	Deposits on outer surfaces of tube and galvanic action	Dezincification and pitting.
6. Shipping firm (Cross Channel).	6	12	80	12 3	Ends of tube	Bottom section	90 to 102	Yes. D.	Zinc tube	Few hours	No definite view	Thinning of tubes and Dezincification and pitting.
7. Shipping firm (Cross Channel).	7	24-25	100	—	Whole length in pits	General	—	No.	Do.	30 to 40 hours	Absence of air in tubes	
8. Same as 7. Another ship.	11	20	Very high	11 4	General, but worst in middle	Do.	—	Yes. D.	Do.	6 hours	Local galvanic action due to settling of particles	
9. Shipping firm (Atlantic trade).	11	11	High	13 8	All both ends	General	100-116	Yes. S.	Do.	8 days	Due to displacement of deposits, but tubes are considered to have stood well	Thinning and dezincification
10. Same as 9. Another ship.	9	11	6.5	11 8½	Near water inlet	Bottom section	93-102	Yes. S.	Do.	7 or 21 days	Local galvanic action	Dezincification and pitting.
11. Same as (9). Another ship.	10	11	10	12 6½	4 in. from each end	Varying	69-95	Yes. S	None	(Life reported as grumpy.		Do.
12. Shipping firm (Cross Channel).	6	—	100	—	Middle	Throughout	128-130	Yes. D	Do.	None suggested		Do.
13. Shipping firm (Cross Channel).	4	—	—	—	Do.	Top section	124	Do.	Do.	20 hours		Do.
14. Shipping firm (Atlantic trade).	5.5	5.5	5.5	13 6½	Do.	—	90-107	Do.	Electro-Anodeum protection	3 weeks	Ditto	Do.
15. Shipping firm (Tropics).	7 (months)	—	14	—	Ends	Bottom section	100	Yes. D.	None	Varying	None suggested; water outside tubes	Thinning and pitting.
LAND INSTALLATIONS.												
16. Paper-mill	8 (weeks)	6-7	11	7 11	About 3 ft. from Middle	Top section	—	—	—	Continuous	None suggested; dock water used	Dezincification and pitting
17. Cotton-mill	—	7	—	—	—	Near one end of tube	75-85	—	—	11½ hours per day	Due to acid in water from canal; fresh water used	
18. Electric power station	2-3	—	8	9 6½	1 ft. from end to centre	Varying	—	—	—	Varying	None suggested; fresh water used	Dezincification and pitting
19. Electric power station	8	8	4	8 1½	Near ends	—	—	—	Iron slabs	Varying	Bad quality of tubes; fresh water used	Dezincification and pitting
20. Flour-mill	8	6	8	8 3½	Middle	—	—	—	Zinc slabs	Varying	Bad quality of tubes and the sticking of bubbles of gas, apparently CO_2, to tubes	Dezincification and pitting

* S. means single-wire system. D. means double-wire system. NOTE.—Where blanks occur, no statement was inserted in schedule.

it from engineers in charge of condensers engaged in practical work, and the general view of the importance of this method has been voiced by Arnold Philip,* who says:

"It is the engineers who are actually responsible for the efficiency of condensers, who are able to provide the necessary information upon which an opinion can be formed as to the causes of observed cases of corrosion,

* Journal of the Institute of Metals, No. 1, 1912, vol. vii, page 51, and "Engineering," vol. xciii, page 99.

and in order to secure that such information is not overlooked at the time, it is very desirable that a suitable schedule of queries be filled in."

In accordance with this view a list of questions relating to condenser-tube corrosion was drawn up and circulated to members of the Institute, superintendent engineers, and others who have the care of condensers under their charge. The list, in the form in which it was finally sent out, was drawn up at a meeting of the Corrosion Committee held during the Newcastle meeting of the Institute. Accompanying the schedule a request was circulated for specimens of condenser tubes that had given good, bad and average service under ordinary conditions of work. A considerable number of forms were returned to the Institute, but comparatively few were completely filled up. Of these, twenty have been selected, and the more important information contained in them has been tabulated in Table I. All the tubes referred to were of 70:30 brass or 70:29:1 alloy. The chief points of interest to be deduced from this table are:

1. The extraordinary variation in the normal life of a tube, viz.: from four to twenty-five years. Supplementary inquiries conducted by the authors have proved conclusively that tubes from the same batch, made by one manufacturer, when placed in different parts of a condenser, might resist corrosion for times which vary up to the proportion of 1 to 3.

2. The peculiar nature of the deterioration that resulted in the failure of the tube. In nearly every case the deterioration was due to dezincification, resulting in a rotten and pitted tube. In two or three cases tubes failed owing to local thinning, due, apparently, to the wearing away of the whole body of the tube near the water-inlet end. This phenomenon was comparatively rare.

3. The impossibility of correlating the failure of the tubes with the presence or nature of the electric-lighting installation.

4. The difficulty of connecting corrosion with any definite locality in the tube or condenser, though it would appear as if thinning were connected with the ends of the tubes at which the cooling water entered.

5. The shorter life of tubes in land installations, where dock, canal or brackish water is used instead of sea water. Nevertheless, the Corrosion Committee, for good reasons, desired investigations in the first instance to be carried out with natural sea water, and this has been used in all experiments described in the present paper, except where the contrary is stated.

A detailed examination of the scale attached to tubes, both good and bad, was made. In normal cases the scale could be regarded as made up of a number of layers of different composition. The top layer consisted principally of ferric oxide, carbonates and chlorides of calcium and magnesium, calcium sulphate, and sand; the next layer consisted of basic chlorides and carbonates of copper and zinc, and was greenish in color. The layer next the tube was brown or black, and consisted largely of cuprous and cupric oxide. There was, of course, no sharp line of demarcation between the various layers, which faded gradually into one another; sometimes the greenish-blue layer was almost absent, especially when dezincification had been severe.

In most cases the scale, particularly the lowest layer, was very strongly adherent to the tube. Owing to the stratification, and the impossibility of removing the scale from the tube without introducing foreign matter, reliable quantitative analyses could not be made; nor, probably, would they have been of much value, since the proportions of sand, ferric oxide, calcium carbonate (in the form of shell), &c., were obviously due to chance. These substances are always present in large and varying quantities, and effectually prevent any useful deductions being drawn from quantitative analyses of the scale. In all cases in which a tube had suffered dezincification, the greenish-blue layer was replaced, to a greater or less extent, by a white flocculent salt, which was found to be a basic chloride of zinc. In one or two cases tubes were received partially

choked with a loosely-adherent deposit, light gray in color. This was found to be principally sand, but contained also ferric oxide, magnesium salts and calcium salts. Such tubes sometimes appeared to be more severely corroded than others taken from the same condenser, but not always.

One particularly interesting case came to hand. This was a 70:30 condenser tube taken from a Yarmouth trawler. It had been in use twenty years, and was apparently as good as new. There was no sign whatever of dezincification or thinning. It was covered with a very hard uniform scale, with a looser finely-reticulated surface layer. There was no well-marked blue-green layer, and this appeared to indicate that very little copper could have been removed from the tube, which, in fact, was practically as thick as when new.

The average total thickness of the scale was 0.31 mm., that of the hard lower layer being 0.13 mm. Analysis showed the latter to consist of oxides of copper and iron and calcium carbonate; no zinc was present. Neither was there any zinc in the looser layer, which consisted of considerable quantities of calcium carbonate and sulphate, together with silica and oxides of copper and iron. The true thickness of the metallic portion of the tube was 1.29 mm., so that, unless the tube had been originally of an unusual thickness, which is improbable, it had not lost more than 0.05 mm. in twenty years.

Careful search was made among the deposits in badly corroded tubes for carbon particles. Although about a hundred cases were examined, no such particles were ever found, and in no single instance could a dezincified spot or area be correlated definitely with such a particle. This, of course, does not prove that carbon in the form of graphite or coal had not started the dezincification of the tube, since it might subsequently have been removed when the tube was cleared by means of an iron rod or brush.

As a result of the study of the answers to the question schedules and of the tubes corroded under conditions of practical work, the authors came to the conclusions that few deductions of importance could be made, and that this method of work is only of value for indicating in a general way the nature of the problem to be attacked.

The chemical and physical conditions obtaining in condensers engaged in practical work are of a complex nature, and may vary considerably from point to point, not only of the condenser as a whole, but even along each tube. Moreover, it is not usually possible to ascertain what are the exact conditions as regards such matters as temperature, speed of water, presence of air, &c., in any particular plant. The possible variations in the conditions from part to part of the same condenser, which might be supposed to cause corresponding variations in the speed of corrosion, may be summarized as follows:—

1. *Variation of the Water Speed in Different Tubes.*—This may operate:
   - A. Directly as an independent effect.
   - B. Indirectly as affecting 2.
   - C. Indirectly as affecting 4.

2. *Variation in the Temperature of the Different Tubes.*—This may operate:
   - A. Directly, owing to increased chemical activity.
   - B. Indirectly, by removing gases from solution (see 6).

   Note.—Choked tubes may become highly heated.

3. *Variation in the Distance of Different Tubes from Electro-Chemical Protector Blocks, Bars, and Main Condenser Bodies.*

4. *Variation in the Distribution of Solid Substances which Settle on the Tubes.*

5. *Variation in the Distribution and Amount of Water left in the Tubes when the Condenser is out of Action.*

6. *Variation in the Oxygen Contained in Solution in the Water during*

its passage through the Condenser.—The concentration will be highest where the water enters, and lowest where it leaves the condenser.

7. *Variation in the Quality of the Water Circulating through the Tubes.* Looking down this list, it becomes obvious that engineers in charge of condensers are not in a position to supply detailed information as to the exact nature of those conditions which may be expected to influence the course of corrosion. Take, for instance, the distribution of temperature. The highest temperature will not necessarily occur at the middle of the top nest of tubes, where the steam usually enters the condenser. It will be influenced by the position and dimensions of baffle plates and by the speed of the water through the tubes. The speed of the water will not necessarily be the same through all the tubes, owing partly to the swirling action in the water ends, and partly to possible partial choking of certain tubes. In any given condenser the distribution of temperature could only be ascertained by direct experiment; and this is not possible without the employment of special apparatus. Moreover, there is an almost entire lack of published experimental work giving quantitative measurements of the effect of these variations on the speed and nature of brass corrosion. Many opinions have been expressed in discussions on the subject, but for the most part they have not been backed by experimental work. Arnold Philip* has on more than one occasion emphasized his view that electro-negative particles of carbon, &c., are of special importance in promoting corrosion, but does not appear to have brought forward any detailed experimental work to support it—perhaps because it seems to be such an eminently reasonable view. Bruhl† also neglected this point, and entirely failed to throw any light on the phenomenon of dezincification, which is the factor of principal importance in practical work. Moreover, with the exception of two experiments carried out at 40 degrees C., he confined all his work to experiments at the ordinary temperature.

Milton and Larke‡ carried out a considerable number of experiments to elucidate dezincification, but for the most part their work was confined to the electro-chemical aspect of the subject. Sinclair§ also worked mainly along electro-chemical lines, but carried out a number of interesting experiments at temperatures higher than atmospheric. Tilden,‖ as long ago as 1886, observed the combined effect of ferric oxide and other substances at a temperature of 40 degrees C. maintained for seven hours a day for eleven months, and probably succeeded in dezincifying his brass. He actually recorded his observations as "deposition of copper," but in view of the knowledge that has been accumulated in more recent years, it seems to the authors probable that he was really observing the phenomenon of dezincification. If this be so, he was probably the first experimenter to observe it in a laboratory experiment.

Section I.

Laboratory Investigation.

Owing to the fragmentary nature of the available experimental evidence, it was deemed advisable to arrange a somewhat extensive laboratory scheme for examining a few of the factors which seemed likely to bear upon the nature and speed of corrosion. In the first place it must be remembered that corrosion phenomena may be divided into two classes:

1. The gradual wearing down of the tube—*i.e.*, general corrosion in which copper and zinc are removed approximately in the proportions in which they occur in the alloy. This action will be called "complete corrosion."

* Journal of the Institute of Metals, No. 1, 1911, vol. v, page 99.
† *Ibid.*, 1911, vol. vi, page 289. "Engineering," vol. xcii, pages 436 and 472.
‡ Journal of the Institution of Civil Engineers, 1903, vol. cliv.
§ *Ibid.*, page 184.
‖ Journal of the Society of Chemical Industries, vol. v, page 84.

2. Dezincification, followed by pitting, in which the zinc is removed preferentially, leaving a pit or area of copper-rich material. Such areas become quite weak and rotten, and in many cases the copper may easily be pushed out of the tube in the form of a plug, leaving a hole. These rotten tubes are no longer watertight.

The action which results in dezincification will be called "selective corrosion." Practically all tubes suffer from the first form of corrosion, although it may be so retarded that the rate becomes practically zero. An instance of this has been cited already.

"Complete corrosion" is sometimes more pronounced at the ends of the tubes, and may even give rise to perforation; but this is a comparatively rare phenomenon. Usually this type of corrosion is comparatively slow, and the vast majority of tubes fail owing to pitting induced by dezincification, before their strength has been seriously diminished by general attack.

It is, therefore, the problem of dezincification that has received the principal attention of the authors, and the problem of perforation by "complete corrosion" has not been specially investigated.

The view has sometimes been expressed that pitting by dezincification is merely ordinary corrosive action intensely accelerated locally, either by the action of electro-negative particles or in some other way. This view presupposes that the normal action of sea water on brass is a slow process of dezincification. The only experimental evidence on the point appears to be that of Sexton,* who states definitely that when 70:30 brass is attacked by sea water, dezincification always occurs. However, this author gives only the very meagre experimental details expected in magazine articles, and in his book on corrosion they are repeated without addition. It seems, therefore, highly desirable to confirm or exclude his conclusions, and this matter served as a starting point for the laboratory research.

Experiments at Atmospheric Temperature, Series I.

The alloys selected for examination were four in number, and were pieces of tube of the same batches as were used in the large-scale experimental plant, which will be described later. Analyses are given later. The tubes were sawn in half and cut into 2-inch lengths, which corresponds to a surface area of 4.2 square inches. The Admiralty tube was of smaller diameter, and hence surface area of 2-inch length was less, = 3.4 square inches. Their edges were filed smooth, and a hole ⅛ inch in diameter was drilled near one end; they were cleaned and polished, and suspended in beakers by means of glass hooks, as shown in Fig. 1, the top of the upper tube being about ½ inch and the lower tube about 3 inches below the surface of the water. Each beaker contained 1½ liters of natural sea water, the surface area of the water being 12½ square inches.

In cleaning the tubes they were roughly polished on the outside with fine emery paper to remove grease, oxide, &c.; the inside surfaces were polished to a rather higher degree by means of circular polishers rotated in a lathe. The purpose of this is explained later. Every endeavor was made to bring all the surfaces to the same degree of polish, so that all the results obtained might be strictly comparable.

The experiments with these tubes served as a basis for the examination of the effect of altering the various conditions. In these experiments the speed of the water was zero. The temperature was the ordinary temperature of the laboratory, averaging 18 degrees to 20 degrees C. No protecting metals or electro-negative particles were present. Normal sea water, taken at high tide outside the port of Liverpool, was used.

* "Engineering Magazine," vol. xxx, 1906, and "The Corrosion and Protection of Metals" (Scientific Publishing Company), page 116.

The oxygen content was simply that which could diffuse down to the tubes from the surface of the water, free access of the air to the beakers being allowed—they were only loosely covered with large sheets of coarse filter paper to keep out dust, &c. The concentration of the sea water was kept constant by adding distilled water from time to time to make good the loss by evaporation.

TABLE II.—SEA-WATER CORROSION RESULTS. FIRST SERIES. UPPER TUBES.

Composition of tube.	Interval.	1. 70 : 30	2. 70 : 28 : 2	3. 61 : 39	4. 70 : 29 : 1
Initial weight in grammes	—	14.7576	14.4914	14.9114	10.8808
Weight after corrosion for	15 days	14.7450	14.4769	14.9034	10.8666
Loss in grammes	—	0.0126	0.0145	0.0080	0.0142
Percentage loss	—	0.08	0.10	0.05	0.13
Weight after	22 days	14.7380	14.4724	14.9018	10.8624
Percentage loss	—	0.13	0.13	0.06	0.17
Weight after	28 days	14.7330	14.4674	14.9020	10.8585
Percentage loss	Sea water renewed.	0.17	0.17	0.06	0.20
Weight after	84 days	14.7100	14.4372	14.8870	10.8204
Percentage loss	Sea water renewed.	0.32	0.37	0.16	0.55
Weight after	168 days	14.6910	14.4126	14.8720	10.7842
Percentage loss	Sea water renewed.	0.45	0.54	0.26	0.89
Weight after	208 days	14.6840	14.4030	14.8645	10.7680
Percentage loss	—	0.50	0.61	0.31	1.04

NOTE.—Owing to the slowness of the attack on the metal and the slowness of the consequent diminution in concentration of the sea water, long intervals were allowed to elapse before renewal.

TABLE III.—SEA-WATER CORROSION RESULTS. FIRST SERIES. LOWER TUBES.

Compostition of tube.	Interval.	1. 70 : 30	2. 70 : 28 : 2	3. 61 : 39	4. 70 : 29 : 1
Initial weight in grammes	—	14.4352	15.6184	15.1424	11.6314
Weight after corrosion for	15 days	14.4235	15.6050	15.1335	11.6174
Loss in grammes	—	0.0117	0.0134	0.0089	0.0140
Percentage loss	—	0.08	0.09	0.06	0.12
Weight after	22 days	14.4192	15.6000	15.1330	11.6130
Percentage loss	—	0.11	0.12	0.06	0.16
Weight after	28 days	14.4148	15.5932	15.1330	11.6092
Percentage loss	Sea water renewed.	0.14	0.16	0.06	0.19
Weight after	84 days	14.3966	15.5636	15.1202	11.5734
Percentage loss	Sea water renewed.	0.27	0.36	0.15	0.50
Weight after	168 days	14.3772	15.5404	15.1066	11.5318
Percentage loss	Sea water renewed.	0.40	0.50	0.24	0.86
Weight after	208 days	14.3705	15.5130	15.1010	11.5130
Percentage loss	—	0.45	0.55	0.27	1.02

The tubes were accurately weighed before examination, and at the end of 15 days were removed, well cleaned by means of a rubber-tipped glass rod, and all loose deposit removed. They were then carefully dried and weighed. They were re-immersed, and further weighings made from time to time. The results are recorded in Tables II and III, and in graphical form in Figs. 2 and 3. The sea water was renewed periodically, as indicated in the tables.

In conducting such experiments as these it has been found necessary to take into account the following factors:

A. The volume, concentration and temperature of the corroding medium.

B. The mode and depth of immersion.

C. The rate of diffusion, whether natural or stimulated artificially by stirring, &c.

D. If diffusion be natural, the superficial area of the sea water surface becomes a factor.

E. Area of exposed surface of corroded metal.

F. The condition of the surface of the corroded metal.

All these factors have been taken into account in the experiments described, and have been kept similar for all tests in each series of experiments. The omission to state their experimental conditions in their published accounts is no doubt responsible for the conflicting results obtained by previous workers.

General Features of the Phenomena Observed.—It soon became clear that the first stage in the corrosion of brass is the oxidation of one or both of the constituent metals. Cohen and others have shown that, in the absence of oxygen, no corrosion will take place, and the authors have confirmed this fact. The earliest visible sign of corrosion is the formation of a layer of brown oxide on the surface of the specimen. Whether or not the oxidation is direct is not a question of importance for the purposes of this paper.

On either view the net result is the same—namely, that the alloy becomes gradually covered with a layer of oxide. This layer is very tenacious, and is not removed by ordinary rubbing with a rubber-tipped glass rod. In the case of 70:30 brass, it is of a reddish-brown color, darkening to a brownish-black as time goes on. The thickness of this layer of oxide is a matter of some importance, as it affects to a certain extent the accuracy of the loss-of-weight method of estimating corrosion. Careful micrometer measurements have shown that it varies from 0.01 mm. in thickness after a few months' immersion to about 0.04 mm. after nine months. *The losses of weight given in all the tables in this paper refer to measurements made with this layer of oxide left adhering to the tubes in an unbroken state, except where the contrary is stated.*

An objection may be raised that this layer of oxide should have been removed by reduction in hydrogen before the final weighing. In some attempted measurements of the thickness of the oxide layer this procedure was carried out, but the results were not satisfactory. The reasons for this were:—(1) that zinc oxide is not reduced at moderate temperatures; and (2) that some zinc was volatilized in the stream of hydrogen gas. As a result, the light powder found on the tube at the end of the experiment was not pure copper and zinc oxide, but finely divided brass, and the loss of weight when this was removed was too great.

After trying a number of alternative methods, such as measuring the reduction of tube thickness and the diminution of the chlorine content of the sea water, the conclusion was reached that the most accurate and satisfactory comparative results would be obtained by weighing all the specimens after corrosion with the oxide layer left unbroken. It was noticed that the formation of oxide did not take place uniformly over the whole surface of the tube. It started at certain areas, irregular in distribution and shape, which could not be correlated with the individual

crystals of the metal. The layer gradually spread until it covered the whole of the surface of the tubes.

It may be of interest to mention here that Lambert,* working with a sample of metallic iron which was probably the purest and most homogeneous metallic substance of any kind that has ever been prepared, showed that even in this case oxidation began at certain spots and then spread outwards. The same result may be observed if a piece of brass tube be heated in a hot-air oven till the surface begins to oxidize. It is evident, therefore, that the very minutest differences, chemical or physical, in a metal, will determine the points at which oxidation begins, but, according to the experiments of the authors, it does not necessarily follow that subsequent corrosive activity will be most pronounced at these same points.

The tubes become tarnished when they have been immersed in water for only a few hours, and a slight bluish opalescence becomes observable in the water. In the course of two or three days a deposit settles to the bottom of the beakers in the form of a fine greenish-blue powder. In the case of Muntz metal the deposit is paler in color, and the surface of the metal exhibits a sallow yellowish tint instead of the reddish-brown color exhibited by the other tubes. The tubes undergo no further change in appearance, but the gradual increase in the amount of deposit shows that the oxide layer is being continually removed and reformed. It appears to be removed by a reaction with the sodium chloride of the sea water, whereby insoluble basic chlorides of copper and zinc are formed.

In certain experiments the greenish-blue deposit was collected and analyzed, and was found to contain the whole of the copper that had been removed from the brass and a large part of the zinc. The remainder of the zinc was present in solution as zinc chloride. The copper and zinc are attacked in approximately the proportions in which they occur in the alloy. The fact that copper is entirely absent from the liquid suggests that the cuprous oxide first formed reacts with the chlorides present in the sea water, forming cuprous chloride or oxychloride. These, being highly insoluble in sea water, are instantly precipitated, thus accounting for the fine bluish opalescence produced so soon after corrosion has started. On the other hand, only part of the zinc forms an insoluble basic chloride, and part remains in solution as normal zinc chloride. As corrosion proceeds, the sea water becomes slightly alkaline, due to the removal of carbon dioxide, which appears to be carried down in the form of basic carbonate. On these views the greenish-blue deposit will be a mixture of basic carbonates and chlorides of copper and zinc, its exact composition varying according to prevailing conditions. As a check on the validity of these views, it was thought desirable to ascertain whether any reaction would take place between sea water and the oxides of copper and zinc prepared by ordinary chemical means. Accordingly, pure cuprous oxide was prepared by the addition of glucose to pure copper sulphate in the presence of tartaric acid. The resulting fine bright-red oxide was placed in a porcelain dish in contact with sea water. No signs of reaction were noticeable for about three weeks, after which time the greenish-blue salt began to make its appearance. Some of the oxide was then placed in a beaker of sea water suspended in a thermostat at 40 degrees C. After two or three days the blue salt, which characterizes the ordinary process of general corrosion, made its appearance.

In view of these results and of the fact that the blue salt is readily formed in all ordinary cases of corrosion at the ordinary temperature, a fresh batch of cuprous oxide was made with a view to ascertaining whether the details of preparation had any effect on the speed of reaction. In this case the oxide was made from pure copper sulphate and glucose without the addition of tartaric acid. The resulting oxide was

* Journal of the Chemical Society, October, 1912, page 206.

lighter in color and had a yellowish tinge. In this state the oxide readily reacted with the sea water at the ordinary temperature, with the formation of the greenish-blue basic salt in the course of a few days.

It was thought desirable to ascertain the composition of the deposit, and for this purpose a suitable quantity was prepared by leaving several feet of 70:30 tube in contact with 4 liters of sea water for several months. The salt does not adhere at all tightly to the tubes, and was washed off, dried, weighed and analyzed. The result was as follows:

	Per Cent.
Copper	40.42
Zinc	13.02
Chlorine	2.95
Carbon dioxide	4.20

Balance: oxygen, magnesium, and calcium salts and insoluble matter. It is evident that the salt is a double basic chloride and carbonate of copper and zinc. It is noticeable that it contains less zinc proportionally to the copper than the original tubes. This is due to the fact that in this and all other experiments on corrosion described in this paper, a part at least of the zinc remains in solution as zinc chloride. The nature of corrosive action in stagnant sea water at the ordinary temperature, and, as will be shown subsequently, at somewhat higher temperatures, may now be summarized as follows:

1. The oxygen in solution* reacts with the copper and zinc of the alloy, forming cuprous oxide and zinc oxide. These substances form first at certain areas. and form a brown or reddish layer which darkens in time (probably owing to the formation of cupric oxide), and which finally completely covers the tube.

2. The oxide layer reacts with the sodium chloride and carbon dioxide of the sea water, the metals thus passing into solution, but instantaneously the whole of the copper and a large part of the zinc are precipitated in the form of a greenish-blue basic salt which is insoluble in sea water, and is usually deposited in a flocculent or non-adhesive state on the tube. The remainder of the zinc remains in solution as chloride.

3. The reaction between the oxide and the sea water probably proceeds at about the same rate as the formation of the oxide, since the oxide layer is always found beneath the greenish-blue salt, but yet only increases very slowly in thickness. Owing to this reaction, the sea water gradually becomes alkaline because of the removal of carbon dioxide.

4. If the tube be allowed to dry, or if the green salt be allowed to remain on the tube for several months, the salt will stick tightly to the tube, but in the latter case only in small isolated patches.

5. The sticking of the salt interferes with the accuracy of loss-of-weight experiments if carried out for very long periods. If violent measures are taken to remove the green salt, the oxide layer beneath is also removed in patches.

6. The experiments described above have been carried out for a period of eight months, and no signs of selective corrosion or local action have been observed. The tubes present a perfectly uniform oxidized appearance indicating progress of complete corrosion only.

In view of the widely-held opinion that "spills" and "flaws" on the interior surfaces of condenser tubes form corrosion centers and start pitting, the inside surfaces of the tubes used in Series I experiments were highly polished, as described previously. The original intention was to examine the polished surfaces under the microscope from time to time as corrosion proceeded, and to try and observe in this way whether corrosion was being accelerated in the neighborhood of any flaws. Micro-

* It is only the oxygen in solution that reacts with the brass, not oxygen in the free gaseous condition.

scopic observation of the metal is effectually prevented by the interposition of the oxide film. Still no evidence was found by this or any other means to show that flaws had any influence on sea-water corrosion at the ordinary temperature. In view of the fact that sea water always contains a considerable quantity of dissolved CO_2 gas, it was thought desirable to ascertain the effect of this substance apart from the presence of salt. Accordingly the following experiment was made:

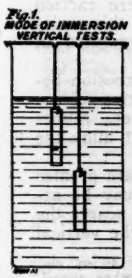
A 3-inch length of 70:30 tube was suspended in 1½ liters distilled water, which was maintained saturated with CO_2 by bubbling a slow stream of the gas through the liquid. The tube was weighed before and after the experiment, which lasted sixty-four days.

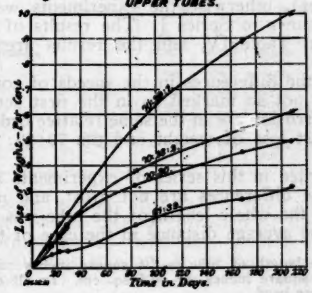
	Grammes.
Weight before experiment	21.0372
Weight after sixty-four days	20.9450
Loss of weight	0.0922
Percentage loss	0.4382

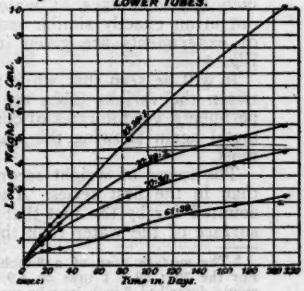
At the conclusion of the experiment the tube presented a dull purplish color, but none of the usual blue-green salt could be seen. The liquid remained clear, but on filtering a trace of green deposit was found. Yet the above result shows that quite a considerable amount of metal was removed; indeed, more than in the case of a similar tube immersed in sea water for the same length of time. Obviously the metal removed must have remained in solution. This was borne out by the observation that on heating the clear liquid to boiling a flocculent white precipitate of basic zinc carbonate was formed. The important point of this experiment is that the loss of metal is almost entirely concentrated on the zinc. It should be mentioned, however, that this form of dezincification takes place uniformly over the whole of the brass, and in this respect is to be distinguished from the type of dezincification referred to later in this paper as "selective corrosion." *Nevertheless, the experiment indicated that waters highly charged with carbon-dioxide gas must have a serious effect on brass.*

Discussion of Results of Experiments in Series I.

Comparison between the results obtained for the upper and lower tubes in the same beakers reveals the fact that in all cases the upper tubes have suffered greater loss in weight. This is only to be expected, since oxygen is an important factor in corrosion phenomena, and is constantly being removed by reaction with the metals of the tube. It can only be







replaced by diffusion from the surface of the liquid, and the new supplies will necessarily reach the upper tubes first. Otherwise the results obtained for the upper and lower tests are in good agreement with one another.

Figs. 2 and 3 show clearly that the Muntz-metal tubes have lost least in weight. Of the others, the 7:29:1 alloy shows the lowest resistance to complete corrosion, whereas the 70:30 and 70:28:2 alloys behave nearly alike, and are rather more resistant. In all cases the rate of corrosion decreases gradually with elapse of time.

These results are surprising. In the first place, it would be expected that the Muntz-metal tube would suffer the greatest loss in weight, since it is a two-phase system, and would therefore appear to be peculiarly liable to electrolytic action. The 7:29:1 metal and the 7:30 brass are homogeneous single-phase systems, and would be expected to show less loss of weight. The 70:28:2 tubes contained a small amount of free lead interspersed between the crystals in a fairly regular manner, and from the electro-chemical point of view might be expected to show a loss of weight intermediate between the Muntz metal and the 70:30 brass.

It is evident that the order of corrodibility of these tubes differs widely from that which would be predicted from the electro-chemical point of view, and the authors conclude that electro-chemical action between the various phases is not an important factor in determining the amount of complete corrosion under the conditions employed in these experiments. The reason for this appears to be that the adherent oxide film, which covers the whole surface of the tubes soon after they have been exposed to the sea water, interposes a considerable resistance into any electrolytic circuit which may at first be formed between the different phases. Consequently the effect of the juxtaposition of two or more phases is completely masked by other factors which influence the speed of corrosion.

Second Series of Experiments.

In view of the unexpected results obtained in the first series of experiments, it was decided to repeat them with slight modifications. The differences consisted in the use of 3-inch* lengths of tube suspended in the beakers horizontally instead of vertically, so that a deposit might rest on the tube instead of falling to the bottom of the beaker, and secondly, in suspending the tubes by means of white string from glass rods laid on the top of the beakers, as shown in Fig. 4. The second modification was merely for the sake of convenience, but the first was carried out to test the effect of the presence of the blue salt on the speed of corrosion. In the first series of experiments this salt fell to the bottom of the beaker, in the second it remained *in situ* on the tubes. Two tubes of the same kind were immersed in each beaker at the same depth (approximately 1 inch below surface of water), otherwise the experiments were carried out in an exactly similar manner to Series I. The results of this series of experiments are given in Table IV, and the results are plotted in Fig. 5.

It will be seen that while the differences in the speeds of corrosion between the various tubes are not so marked as in the first series of experiments, yet the rates of corrosion are in the same relative order. Muntz metal again showing the least loss of weight and the 70:29:1 alloy the most.

The losses of weight recorded in this series of experiments are greater than in the first series. The differences are not great, and may be accounted for by the fact that the whole length of the tube was nearer the surface of the water than the average distance in the case of the vertical

* The surface area of a 3-inch length of tube is 6.4 square inches = 40 sq. cm. For the 70 : 29 : 1 tube = 4.9 square inches, or 30.5 sq. cm. In all other experiments described 3-inch lengths were used.

TABLE IV.—Sea-Water Corrosion Experiments. Second Series.

—	Interval.	1. 70 : 30		2. 70 : 29 : 1		3. 69 : 31		4. 70 : 29 : 1	
		A.* (Horizontal).	B. (Vertical).	A.	B.	A.	B.	A.	B.
Initial weight in grammes ..	—	22.3662	22.6020	23.6705	23.8400	22.8060	22.7026	15.2020	16.1422
Weight after corrosion for	30 days	22.3122	22.7025	23.6843	23.4864	22.5780	22.6812	15.2000	16.1407
Loss in grammes	—	0.0540	0.0455	0 0063	0.0445	0.0180	0.0186	0.0280	0.0241
Percentage loss	Sea-water renewed	0.24	0.20	0.27	0.19	0.08	0.08	0.12	0.21
Weight after	60 days	22.3210	22.7444	23.5695	23.4022	22.5640	22.6988	15.2774	16 0-75
Percentage loss	Sea-water renewed	0.24	0.23	0.32	0.31	0.17	0.17	0.26	0.34
Weight after	90 days	22.3700	22.7225	23.5695	23.4418	22.5360	22.6428	15.2646	16.0675
Percentage loss	Sea-water renewed	0.43	0.32	0.43	0.43	0.26	0.25	0 30	0.47
Weight after	120 days	22.2270	22.6930	23.5585	23.4100	22.5110	22.6020	15.2580	16 0480
Percentage loss	—	0.62	0.36	0.56	0.55	0.37	0.36	0.43	0.61

* The tube-pieces A and B belonging to tube 1 were immersed in same beaker in different ways—A horizontally and B vertically, and this is reflected in the results.

TABLE V.—Concentrated Sea-Water Corrosion Experiments.

—	Interval.	No. 1 in 4 Litres Ordinary Sea-Water.		No. 1 in 1½ litres Sea-Water of Concentration 1.5		No. 1 in 1½ litres Sea-Water of Concentration 2.		No. 1 in 1½ Litres Sea-Water of Concentration 4.	
		A.	B.	I.	J.	K.	L.	M.	O.
Initial weight in grammes ..	—	20.5500	20.1850	22.7810	22.9080	20.8436	20.0880	21.3-91	21.7464
Weight after corrosion for	30 days	20.5156	20.1408	22.7512	22.9222	20.7960	20.0905	21.3240	21.7151
Loss in grammes	—	0.0422	0.0444	0.0498	0.0458	0.0 96	0.0026	0.0814	0.0703
Percentage loss	Sea-water renewed	0.21	0.22	0.22	0.20	0.29	0.79	0.29	0.32
Weight after	60 days	20.4964	20.1318	22.7054	22.8862	20.7418	20.0845	21.3794	21.6878
Percentage loss	Sea-water renewed	0.31	0.31	0.32	0.30	0.49	0.58	0.51	0.56
Weight after	90 days	20.4576	20.0856	22.6340	22.8760	20.7058	20.3275	21.3288	21.6089
Percentage loss	Sea-water renewed	0.49	0.49	0.43	0.41	0.66	0.70	0 75	0.84
Weight after	120 days	20.4125	20.0510	22.6555	22.8595	20.6570	20.8510	21.1730	21.5430
Percentage loss	—	0.71	0.67	0.55	0.56	0.85	0.88	1.01	1.06

TABLE VII.—Influence of Particles and Deposits on Sea-Water Corrosion.

Details of Treatment.	Interval.	Weight Before.	Weight After.	Loss.	Percentage Loss.	
		grammes.	grammes	grammes		
1. 70 : 30 tube alone in 1½ litres sea-water immersed horizontally (check)	30 days	21.4872	21.3210	0.1162	0.54	Check.
2. Tube similar to above in 1½ litres of sea-water with pieces of graphite and coke tied on to interior surface	30 ,,	22.1156	22.0600	0.0556	0.25	Graphite and coke.
3. Tube treated similarly with pieces of clinker and iron pyrites on surface	30 ,,	20.9635	20.8735	0.0783	0.37	Clinker and pyrites.
4. Check tube .. .. Both immersed in	45 ,,	18.5432	18.5098	0.0295	0.21	Check.
Tube with sand laid on surface 1½ litres sea-water		18.4648	18.4332	0.0256	0.16	Sand.
5. Check tube .. .. Both immersed in	8 ,,	20.2756	20.2580	0.0166	0.08	Check.
Tube in contact with freshly-prepared Fe_2O_3 1½ litres sea-water		20.4870	20.4641	0.0229	0.11	Fe_2O_3 (fresh).
6. Check tube .. .. Both placed horizontally in sea-water	15 ,,	18.4078	18.3814	0.0264	0.14	Check.
Similar tube and ignited Fe_2O_3		18.4648	18.4300	0.0648	0.19	Fe_2O_3 (ignited).
7. Check tube .. .. Both immersed	45 ,,	18.9846	18.9115	0.0631	0.23	Check.
Tube with deposit formed on surface by evaporation of sea-water at ordinary temperature horizontally in 1½ litres sea-water		24.4256	24.3240	0.1016	0.42	Sea-water deposit.
8. Tube with sea-water deposit formed as above, but then baked for 9 hours at 55 deg. C. Both placed in 1½ litres sea-water	45 ,,	19.6042	19.4965	0.1067	0.55	Baked deposit 55 deg
Tube with sea-water deposit baked 9 hours at 100 deg. C. ..		19.6806	19.5440	0.1163	0.59	Ditto, 100 deg.

TABLE VIII.—Tests at 40 Deg. Cent.

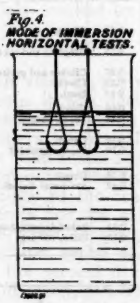
—	Interval.	1. 70 : 30		2. 70 : 29 : 1		3. 69 : 30.		4. 70 : 29 : 1.	
		A.	B.	A.	B.	A.	B.	A.	B.
Initial weight in grammes ..	—	19.0271	20.7267	22.3662	23.6438	21.6240	21.8845	16.1612	13.7071
Weight after	7 days	19 0210	20.7250	22.3626	23.6156	21.6277	21.8820	16.1584	13.6980
Loss in weight	—	0.0261	0.0017	0.0240	0.0270	0.0263	0.0025	0.0146	0.0181
Percentage loss	—	0.13	0.11	0.11	0.13	0.08	0.025	0.08	0.09
Weight after	14 days	18.9983	20.6982	22.3185	23.5923	21.6270	21.8276	16.1432	13.6675
Percentage loss	—	0.18	0.14	0.16	0.19	0.085	0.08	0.09	0.10
Weight after	28 days	18 9980	20.6955	22.3040	23.5830	21.6145	21.8130	16.1360	13.6640
Percentage loss	Sea-Water renewed	0.21	0.19	0 23	0.23	0.085	0.10	0.13	0.13
Weight after	35 days	18.9215	20.6830	22.2985	23.5710	21.6115	21.8106	16.1340	13.6610
Percentage loss	—	0.24	0.21	0.23	0.21	0.11	0.11	0.14	0.14

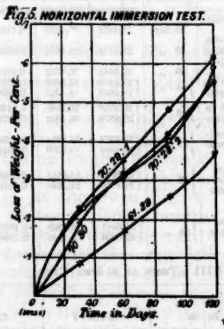
tubes. It seems unlikely that the presence of the blue salt has any important effect on the rate of corrosion of the tubes.

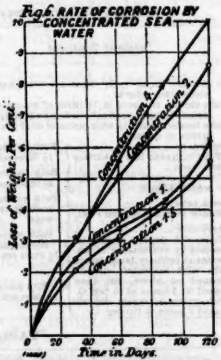
It has been suggested from time to time by engineers and others that sea water remaining stagnant in the tubes has a specially rapid corroding effect on them. The second series of experiments shows that a 70 : 30 brass tube loses about 0.6 per cent. of its weight under the action of sea

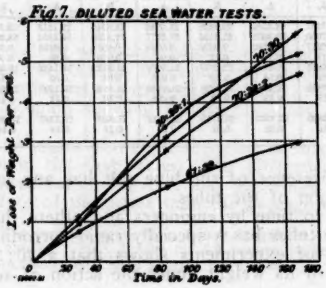
water for four months at the ordinary temperature. Supposing no pitting to take place, and assuming that a tube could be used till it had lost two-thirds of its thickness, that corrosion takes place on one side only of the tube, and that it proceeds uniformly at the same rate, the life of a 70:30 tube should be about seventy-five years. In practice, the life of a tube rarely reaches twenty-five years, and the normal life of a tube may be taken to be about twelve years under average conditions. As a matter of fact, the life of a tube in practice is usually limited, not by its resistance to thinning, but by local dezincification and pitting. Only complete corrosion occurred in these two series of experiments, and therefore the experiments hitherto described throw but little light on the practical problem, except by showing that stagnant sea water at the ordinary temperature is not of itself an important source of trouble.

Influence of Concentration of Sea Water.—Condenser tubes are occasionally submitted to the action of sea water containing salts of a different concentration from the normal. Thus, when sailing up rivers and estuaries the water pumped through the condensers may contain much less salt than water from the open sea. On the other hand, drops of water may lie along the bottom of the tubes when the condenser is out of action and partially evaporate, giving rise to a concentrated solution of sea-water salt. Further, such drops of concentrated sea water may be formed always in the same positions in the tubes. Consequently it was thought desirable to obtain data showing the effect of these factors.









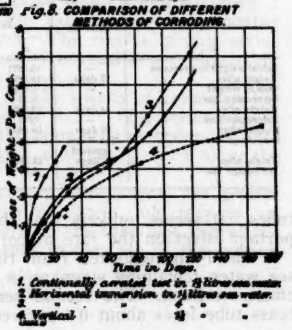


Fig.8. COMPARISON OF DIFFERENT METHODS OF CORRODING.
Loss of Weight - Per Cent.
Time in Days.
1. Continually aerated test in ½ litre sea water.
2. Horizontal immersion in ½ litre sea water.
4. Vertical

The experiments were carried out as before, with the exception that the liquid used was sea water which had been concentrated to one-quarter. one-half, and three-quarters of its original volume, and a fourth test was made with sea water which had been diluted to twice its volume with distilled water. Thus calling the concentration of ordinary sea water 1, the concentration of the liquids used could be denoted by 4, 2, 1.5 and 0.5 respectively. Only one kind of tube was used in the experiments with concentrated sea water, viz.: 70:30 brass. Two tubes were immersed horizontally in each kind of sea water exactly as in Series II. The results are shown in Table V, and Fig. 6.

It will be seen that in general an increase of concentration gives an increase in the rate of complete corrosion. Between sea water of concentrations 1 and 1.5 there is little difference in rate of attack; but the higher concentrations 2 and 4 accelerate it to almost twice the ordinary rate. The corrosion product was the ordinary blue deposit already described. No signs of dezincification were observed.

There was a noticeable difference from the usual appearance in the case of the tubes which were corroded in the highly concentrated sea water. The oxide layer was much lighter in color; and the greenish deposit adhered to the tubes tightly in patches, rendering the loss-of-weight values less accurate. The deposit, on the other hand, was more highly colored, indicating that there was less copper in the oxide layer, but more in the deposit.

A series of tests with the four types of tube suspended vertically (using 2-inch lengths), precisely similar to Series I experiments, was carried out in diluted sea water (concentration 0.5). The results obtained for the upper tubes are given in Table VI and Fig. 7.

TABLE VI.—DILUTED SEA-WATER CORROSION TESTS.

.....	Interval.	1. 70 : 30	2. 70 : 28 : 2	3. 61 : 39	4. 70 : 29 : 1
Initial weight in grammes	...	12.1652	13.8800	13.3290	9.6500
Weight after corrosion for	28 days	12.1514	13.8668	13.3197	9.6408
Loss in grammes.....	...	0.0138	0.0132	0.0093	0.0092
Percentage loss.....	Sea water renewed.	0.11	0.095	0.07	0.095
Weight after.....	84 days	12.1274	13.8415	13.3044	9.6172
Percentage loss.....	Sea water renewed.	0.31	0.28	0.18	0.34
Weight after.....	168 days	12.0960	13.8150	13.2895	9.6000
Percentage loss.....	...	0.57	0.47	0.30	0.52

They show that a decrease in the concentration of the sea water diminishes slightly the rate of complete corrosion. A complicating factor, however, is introduced by the fact that after the lapse of five to six months a new type of corrosion is observed to set in. The tubes (with the exception of the 70:28:2 alloy) which had hitherto undergone only ordinary complete corrosion of the kind previously described became covered (mostly on the backs) with minute specks of a white substance, which was strongly adherent. When the white salt was removed a coppery area was invariably disclosed. Evidently the corrosion was proceeding in a different manner from usual, and was of the type characterized in this paper as "selective." This aspect of corrosion is dealt with in detail later. It is very noteworthy that the 70:28:2 brass did not show any sign of this selective attack under these conditions, while, of the others, Muntz metal seemed to be the most suspectible to it.

Influence of Particles.

The opinion has been repeatedly expressed by speakers and writers on corrosion that trouble occurs most frequently in practice when sea water has been allowed to remain at rest in the tubes. Arnold Philip, in particular, has suggested that stagnant sea water gives rise to serious corrosion, but acts principally by allowing particles of carbon and other electro-negative bodies to remain at rest in one position on the tube, thus giving rise to intense local electro-chemical action.

In the early stages of the research it seemed to the authors probable that some such action might be the cause of the dezincification of tubes, and experiments were arranged to test the effect of the following substances, acting in conjunction with stagnant sea water at atmospheric temperatures: Graphite, coal, coke, clinker, sand, iron pyrites; loss-of-weight experiments were carried out in exactly the same manner as in Series II experiments previously described, the various substances being placed on the tubes, which were all of the 70:30 type. In the case of coal, coke, &c., the materials were tied firmly down to the tubes, so as to touch them to certain definite points. Check tubes—*i.e.*, tubes without any substance in contact with them—were placed in the same beakers with the tubes being tested. The results are collected in Table VII.

These results show that none of the substances examined exerts any important influence on the amount of general corrosion at the ordinary temperature. Moreover, the most careful scrutiny of the tubes failed to reveal any sign of dezincification. In general, the effect of these substances was to retard slightly the speed of corrosion. Under the graphite and sand the tubes were quite bright and unoxidized, and it seemed that the only effect of these substances was a mechanical one, whereby free access of oxygen to the tube was prevented. It seemed just possible that the bright areas of the tubes were really areas of most active attack, from which oxide was removed more rapidly than it was formed, but careful micrometer measurements show that in every case tubes were slightly thicker at the bright areas than at the surrounding parts.

These experiments as regards the effect of graphite were repeated with pieces of Admiralty tube, and exactly similar results obtained.

It seemed probable that the failure of such substances as graphite and coal, even when in close contact with the tubes, to promote corrosion, was due to the resistance interposed in the electrical circuit at the point of contact between the tube and carbon. To test further the efficacy of electro-chemical action the following experiment was also made:

A circular hole was bored in a piece of 70:30 brass tube, and a piece of copper rod was screwed into it, thus ensuring a thoroughly satisfactory electrical contact between the electro-negative copper and the electro-positive brass. The tube was then immersed in stagnant sea water for sixty days, together with a check tube. The results of loss-of-weight determinations were as follows:

Loss after 60 Days =	
Copper Plug Tube.	Check Tube.
Per Cent.	Per Cent.
0.23	0.25

There was no sign whatever of any localized reaction on the brass surrounding the copper, such as would have occurred if any electro-chemical stimulation of corrosion had taken place. The conclusion to be drawn from this and other experiments to be described subsequently is that, even under the most favorable conditions that can be devised to exhibit electro-chemical attack on brass by carbon and copper, no such action takes place, and that in consequence the settling of particles on condenser tubes is not *per se* a cause either of dezincification or of any intense local complete corrosion inducing a pit.

The authors attribute the absence of such action to the contact resistance interposed in the electrical circuit by the adherent oxide film which forms on the surface of the brass. *The existence of electro-chemical action*, which a number of authors claim to have described in the case of iron and steel, *is due to the fact that the hydrated ferric oxide does not adhere to the surface of the metals and that in consequence electro-chemical action can proceed freely without the interruption due to the introduction into the circuit of a large amount of resistance.*

Influence of Motion of Sea Water.—In all the experiments hitherto described the rate of complete corrosion has been very slow. It follows, however, from the nature of the reaction as outlined above that if the sea water were kept continually in motion, as is the case of condensers, it would be considerably accelerated. In stagnant sea water the layer in contact with the oxide film will quickly become impoverished in salt by reaction with the oxide, and fresh salt can only reach the tubes by the slow process of diffusion. Thus it has been found, by daily weighing experiments conducted on tubes suspended in stagnant water, that the rate of corrosion is always much faster during the first day than afterwards. At first, the rate is determined by the speed of reaction between the oxide and the salt, but after the first few hours it is determined principally by the rate of diffusion of salt and oxygen, and since this is slow the speed of corrosion falls off considerably. Possibly the zinc passes rapidly into solution during the interval of time before the formation of the oxide layer. These points are illustrated by the curves shown in Figs. 8 and 9.

Curve 1, Fig. 8, shows the results obtained from a continuous aeration experiment, in which two 70:30 tubes were immersed in 1½ liters of sea water, through which air was kept continually bubbling, and thereby the speed of corrosion is almost doubled compared to the rate of corrosion in stagnant sea water, as represented by curves 2, 3 and 4.

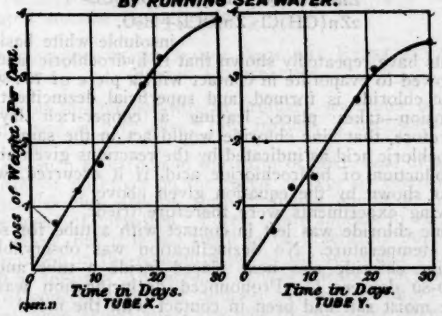


Fig. 9. RESULTS OF CORROSION BY RUNNING SEA WATER.

The curves shown in Fig. 9 were obtained from the results of an experiment in which 4 liters of sea water were circulated continuously by means of a pump along two 6-inch lengths of 70:30 tube which had been cut in half along a diameter. Under these conditions the speed of corrosion is further increased to approximately four times the rate obtaining in stagnant sea water (an accurate comparison cannot be made, since only a portion of one side of the tubes was exposed to attack by the flowing current of sea water). A uniform tenacious oxide layer was formed on these tubes similar to that on the tubes immersed in stagnant sea water, but was somewhat darker in color.

Further experiments were carried out with circulating sea water on the

effect (if any) of particles on brass corrosion. Pieces of coal and clinker were tied on near the center to 6-inch lengths of each of the four kinds of tube, and sea water circulated along the tubes continuously for thirty days. On examination at the end of this time, none of the tubes showed any traces of localized corrosion in the neighborhood of the particles. On the other hand, beneath the coal was found a bright unoxidized patch, confirming previous observations that such particles only exert a mechanical protective action.

Influence of Deposits of Basic Salts.—In view of the fact that neither copper nor carbon particles set up any electrolytic action when in contact with a tube, it seemed unlikely that such poor conductors of electricity as the green basic salts which are formed during corrosion would have any effect. There still remains the possibility that they might exert direct chemical or catalytic action.

In the horizontal immersion tests, when the ordinary green deposit was allowed to settle on the tubes its influence was shown to be very slight. In this case, however, the deposit never adhered tightly to the tube. In order to test whether it would exert a greater effect when it adhered firmly to a tube, a wet-and-dry test was carried out by immersing two tubes for one day in sea water, and allowing them to dry in air on the next, and so on alternately for sixty days.

The results showed an increased loss of weight as compared with the ordinary continuous immersion tests, but no signs of selective corrosion were observed. Hence it may be concluded that at ordinary temperatures the greenish-blue deposit does not give rise to selective corrosion.

It has already been mentioned that a portion of the zinc which is removed from the tube in the course of the complete type of corrosion remains in solution as chloride. It is well known that this substance in aqueous solution has an acid reaction, owing to hydrolysis, thus—

$$ZnCl_2 + 2H_2O \gtrless Zn(OH)_2 + 2HCl.$$

On concentration of the aqueous solution—

$$ZnCl_2 + H_2O \gtrless HCl + Zn(OH)Cl.$$

$$2Zn(OH)Cl > Zn_2OCl_2 + H_2O.$$

insoluble white basic chloride.

Experiments have repeatedly shown that if hydrochloric acid, even when dilute, be allowed to evaporate in contact with a piece of 70:30 brass tube, a green basic chloride is formed, and superficial dezincification—*i.e.*, selective corrosion—takes place, leaving a copper-rich layer. It was thought, therefore, that zinc chloride would act in the same way by generating hydrochloric acid as indicated by the reactions given above. Moreover, the production of hydrochloride acid, if it occurred, would be regenerative, as shown by the equation given above.

The following experiments were therefore tried:

1. Moist zinc chloride was left in contact with a tube for some days at the ordinary temperature. No dezincification was observable.

2. Moist zinc chloride was next placed inside a tube and the whole heated to 70-80 degrees C. Pronounced dezincification was observable wherever the moist salt had been in contact with the metal.

3. Zinc chloride was placed upon a tube suspended in ordinary sea water. No selective corrosion occurred, but the tube did not oxidize, retaining its yellowish color as if protected from corrosion.

It is evident, therefore, that zinc chloride, if it can accumulate at any point on a tube, might start dezincification if the condenser tubes were hot. It is not, however, very easy to see in what way this salt can accumulate at any one definite spot. The most probable way seems to be as follows: Drops of concentrated water might form many times in a certain definite position on a tube when the condenser was emptied, these might finally dry up and give rise each time to a considerable amount of basic salt which might be rich in zinc chloride. In the presence of fresh supplies of moisture the chloride might be hydrolyzed and give rise to dezincification.

Accordingly, the following experiments were tried: Drops of sea water were placed on three tubes and allowed to evaporate completely. As soon as this occurred the drops were renewed, and in this way a quantity of basic salt was accumulated at certain points on the tubes. One of the tubes was then heated to 55 degrees C., another to 100 degrees C., and a third was not heated at all. The deposits on the three tubes would thus represent three states of basicity—that heated to 100 degrees C. being the most basic. Next, they were all immersed in sea water for four weeks. Corrosion of the complete type increased with the degree of the basicity of the salt, but no dezincification or selective corrosion was observable.

A number of other similar experiments with various deposits of basic salts were tried. In some cases these appeared to have some slight influence on the rate of complete corrosion, but in no case was the influence sufficient to exert any appreciable effect on the life of the tube.

Experiments with Jelly Indicator.

It was thought that some light might be thrown on the phenomena of dezincification by the use of a test similar to that used by Walker and others for studying the corrosion of iron and steel, and called by them the ferroxyl test.

The test was originally devised for the purpose of ascertaining at what particular area on a sample of metal iron passed into solution with the formation of rust. The test was carried out in exactly the same manner as for iron and steel, except that potassium ferrocyanide was substituted for potassium ferricyanide, since the former gives an easily recognizable white precipitate with zinc and a brownish-red precipitate with copper.

Experiments were carried out with jellies made up with distilled water and sea water. Ordinary pieces of 70:30 tube, when tested in these jellies, showed no well-defined local action. In both cases the jellies showed metal passing uniformly into solution with production of a pink phenolphthalein coloration all over and around the tubes. After immersion in the jelly for a few days the tubes became covered with a slimy brown layer of the precipitated metallic ferrocyanide.

General Conclusions to be Drawn from the Experiments at Atmospheric Temperature.

1. Corrosion at this temperature in ordinary sea water is always of the complete type and is very slow, and, further, it decreases in rate with progress of time.

2. Particles—such as carbon in the form of coke, coal or graphite, sand, &c.—have little or no effect on the speed or type of corrosion.

3. The greenish-blue deposit formed during corrosion has very little effect on the speed of corrosion. Ferric oxide appears to exert some slight accelerating effect, but it is too small to be practically important.

4. The alteration in the concentration of the sea water affects the speed of corrosion as follows: An increase of concentration increases the speed; a decrease of concentration (or dilution of the sea water) decreases the speed, and to some extent alters the type of corrosion after a long period of immersion.

5. No evidence is forthcoming that "flaws" and "spills" have any influence on corrosion at ordinary temperatures.

6. The rate of corrosion is approximately the same in the case of 70:30 brass and the 70:28:2 alloy. The rate of corrosion of Muntz metal is slower, and that of the 70:29:1 alloy is faster than that of the other alloys.

The order of resistance to selective corrosion, induced by diluted sea water, showed the 70:28:2 brass to be the most resistant (to date has resisted completely), and Muntz metal the least resistant.

8. Free hydrochloric acid will give rise to corrosion of the selective

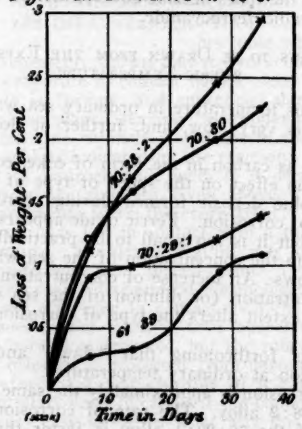
type at the ordinary temperature, but is either not formed at all from zinc chloride in the presence of sea water, or is formed in too small a quantity to be harmful.

Experiments Carried Out at 40 Degrees C.

For these experiments a large gas-heated thermostat, which would hold sixteen beakers, was fitted up. In each beaker was placed 1½ liters of sea water, and they were suspended in the thermostat by means of wooden trays. The surface of the water in the beakers was left open to the air, and evaporation was made good each day by means of distilled water. The water surrounding the beakers in the thermostat itself was covered with a layer of liquid vaseline to diminish evaporation. The temperature of the thermostat remained constant to within a quarter of a degree, and this was sufficiently accurate for the purpose in view. A pair of 3-inch lengths of each of the four standard tubes were immersed in four of the beakers, in a precisely similar manner to that described in the horizontal immersion tests. The thermostat was heated continually night and day and throughout the week ends.

The first stage of corrosion appeared to be identical with that which occurs at the ordinary temperature, viz.: oxidation of the surface of the tubes, but the layer of oxide was formed more rapidly; Muntz metal must be excepted from this statement, since the metal appeared quite bright and unoxidized. The second stage of the process was the formation of an insoluble green deposit which contained both copper and zinc, and closely resembled that formed at the ordinary temperature. As before, part of the zinc remained in solution. The tubes were removed and weighed every week, and the results are shown in Table VIII, and are plotted in the curves shown in Fig. 10. It will be seen that the order in which the tubes resist corrosion at 40 degrees C. differs from that at atmospheric temperature.

Fig. 10. EXPERIMENTS AT 40°C.



In a number of the experiments at 40 degrees C. dezincification was observed. Whenever this occurred a white salt was formed in addition to the greenish-blue salt already described. The white salt was found to be oxychloride of zinc, and it adhered firmly to the tubes in spots. In consequence of this the losses of weight in these experiments

are not so reliable a measure of the amount of corrosion as in the experiments conducted at the ordinary temperature.

The first tubes to show signs of dezincification were those of Muntz metal. An adherent white deposit, sticking to the tube in small patches at the edges and at the ends, was clearly visible at the end of seven days. Beneath each white speck a small dezincified area was found. The rest of the tube retained its bright appearance. The dezincified spots increased in number as time went on, and at the end of a month the greater part of the edges and ends of the tube were coppery in appearance. Dezincification had also begun on the backs of the tubes.

The next to show dezincification was the 70:30 brass. It was noticed on one of the two tubes at the end of a fortnight, but the other was apparently not affected. At the end of a month, however, dezincification was quite marked along the edges and ends of both tubes and on the back of one only.

The 70:29:1 tubes showed slight traces of dezincification at the end of three weeks. In the case of these tubes it occurred on the interior surfaces near the end.

The 70:28:2 tubes appeared to be the most resistant to selective corrosion. At the end of a month there were but very slight traces of dezincification along the sides of the interior surfaces of the tubes.

A considerable number of other experiments were carried out at 40 degrees C. on 70:30 brass tubes. It was observed that in the great majority of cases dezincification began along the sawn edges of the tubes. Two explanations of this observation suggested themselves. In the first place, it was just at these edges that diffusion, both of oxygen and salt, took place most rapidly, and this fact alone might be sufficient to account for the increased action in that position. An alternative view was that these edges, which had been sawn and only roughly smoothed, afforded better *loci* for the deposition of the white basic salt, which in some way facilitated the attack on the zinc of the brass.

To test the latter view two tubes were polished all over very carefully, so that the physical condition of the edges and ends was as nearly as possible identical with that of the inner surface. These tubes were then placed in a beaker in the thermostat along with the other tests. At the end of a month it was found that one of the tubes showed severe dezincification along one edge only, while the other tube was dezincified only along the bottom edge of the inner surface, and not at all along the edges. The result is not entirely conclusive, but, taken in conjunction with the results obtained with other tubes, appears to point to the fact that the physical condition of the surface exerts some influence in determining the areas at which dezincification appears.

Influence of Concentration of Sea Water at 40 Degrees C.—The samples of the sea water used in this section of the work were of concentration 0.5 (diluted sea water) and 2.

In the case of the diluted sea water both tubes clearly showed dezincification at the end of seven days, and at the end of one month it had become fairly general all over the tubes; patches of the white basic salt were widely distributed. In the case of the concentrated sea water, the tubes at the end of a fortnight exhibited a light yellowish-brown oxidized appearance; no particles of white salt adhered to the tubes, nor was any sign of dezincification visible on either tube. After a period of one month white spots began to appear, showing that concentrated sea water has a retarding, but not preventative, effect on the occurrence of selective corrosion.

INFLUENCE OF SUBSTANCES IN CONTACT WITH TUBES AT 40 DEGREES C.

(A) *Graphite on 70:30 Tubes.*—After twenty-eight days the tube was bright and unattacked beneath the graphite. At the edges of the graphite, layers of bluish and reddish oxide were visible. These were evidently

due to the mechanical prevention of diffusion by the graphite, whereby the salt was unable to attack the oxide. The tubes showed dezincification in spots, mainly along the edges, as in the case of the bare tubes discussed above. The locality of the spots showed no definite relation to the position of the graphite.

Graphite on 70 : 29 : 1 *Tubes.*—The appearances presented by these were similar to those of the 70 : 30 tubes, except that no dezincification was observable.

(B) *Copper Plug Experiment.*—A 70 : 30 tube, with a copper plug screwed into it, was placed in a beaker with a check tube; at the end of a month both tubes exhibited general dezincification at the edges. The metal in the neighborhood of the copper plug was not specially attacked. The presence of the copper plug evidently had no effect on the distribution of the areas of selective corrosion. The plug itself was covered with a layer of cuprous oxide.

(C) *Precipitated Zinc Hydroxide.*—It was thought that a slow interaction might take place between this substance and the salt in sea water and give rise to the oxychloride, which is formed as a result of selective corrosion, and which appears to have an accelerating, or, at least, localizing, effect upon the reaction. Accordingly a check tube and a tube upon which zinc hydroxide had been placed were exposed to the action of sea water for a month at 40 degrees C. A slight dezincifying action was observed beneath the hydroxide deposit, and it seemed probable that the expected reaction took place to some extent, but was slow and required a considerable time to become effective.

(D) *Ferric Oxide.*—This substance seemed to have a slightly accelerating effect on the rate of complete corrosion, as noticed previously for corrosion at atmospheric temperature. It did not appear to increase selective corrosion.

(E) *Zinc Chloride.*—This substance when brought into contact with sea water formed a highly insoluble finely-divided oxychloride which settled on the tubes and set up active dezincification. The action was most intense at the edges, which became uniformly coppery in color. No complete corrosion took place, the tubes retaining their bright yellow color, and their loss in weight was much smaller than in the normal case.

Consideration of the Results of Experiments at 40 Degrees C.

One fact of predominating importance has been brought out by these experiments, viz.: that brass tubes of any of the standard compositions will become dezincified by the action of sea water at this temperature. The order of resistance to this type of corrosion is:

1. Muntz metal (the least resistant).
2. 70 : 30 brass.
3. 70 : 29 : 1.
4. 70 : 28 : 2.

Dilution of the sea water increases the tendency towards selective corrosion; concentration of the sea water tends to repress it. The effect of particles was unimportant, with the exception of zinc chloride and possibly zinc hydroxide. The position at which dezincification began was determined largely by the physical condition of the metal and by the points to which diffusion could take place most rapidly, and not by the electrochemical effect of particles.

In no case were the tubes dezincified to any great depth by immersion for one month, and the experiments must be continued for a much longer period before a quantitative expression can be obtained for the rate of progress of dezincification through the tube. Although at 40 degrees C. the type of corrosion is selective to some extent, yet it is not entirely concentrated upon the zinc. In all cases a certain amount of loosely adherent

greenish-blue salt was formed, which closely resembled that observed at the ordinary temperature. The formation of this salt did not appear to be confined to definite parts of the tube, but to take place generally, except just at those points where dezincification was in progress. On the other hand, dezincification began at certain definite spots and spread gradually. At these spots white basic chloride of zinc was formed and adhered firmly to the tubes. The nature of the action seems to the authors to be as follows:

At 40 degrees C. the normal action of sea water is slight preferential solution of the zinc, but some copper is removed from the metal at the same time. The zinc chloride, which rapidly accumulates in the solution, reacts with oxygen to form a basic oxychloride, which is precipitated upon the tube at any point of roughness, or on any particles of foreign matter which themselves stick to, or slightly roughen, the tube, and so present nuclei for the precipitation of the salt. When once this white salt has been deposited at any point, the action becomes localized, and it seems as if the salt has a regenerative action in bringing about the transfer of chlorine from the sea water to the zinc of the brass.

It is now abundantly evident that temperature is a factor of prime importance in determining the type of corrosion of brass at 40 degrees C. Even at 25 degrees C.—that is, at only a slight elevation above the ordinary temperature—it has been found that selective corrosion of 70:30 brass becomes visible after a few weeks' immersion in sea water. It is a remarkable fact that Bruhl mentions the result of two loss-of-weight experiments carried out for nine weeks with 70:30 brass, but gives no details of the appearance of the tubes, and makes no mention of dezincification, nor does he refer to any difficulty met with in removing oxychlorides. No analysis or description of the brass used, or details of the method of experiment are given in his paper, but the metal appears to have been brass plate. The present authors have observed dezincification at 40 degrees C. in twenty different samples of tube, and only one sample successfully resisted it for a month. It should perhaps be mentioned that Bruhl used synthetic sea water, whereas the authors used natural sea water.

Relation Between Loss of Weight and the Occurrence of Dezincification.

An examination of the tables and curves will show that the loss of weight for a given time of immersion in the case of 69:31 and 70:28:2 alloys is slightly greater at 40 degrees than at the ordinary temperature, while in the case of 70:30 alloy it is about the same, but much smaller for Admiralty metal, so that the relative order in which the tubes lose weight differs from the order at the ordinary temperature. Moreover, there is no definite relationship between the total loss of weight and the resistance to dezincification. Thus Muntz metal, which loses least in weight, is most readily dezincified; as regards loss of weight it is followed by the 70:28:2 alloy, but the 70:30 brass is the next most easily dezincified tube.

It should be borne in mind that in all cases in which dezincification takes place, the loss-of-weight results are less accurate than when no such action takes place. It is, however, quite evident that loss-of-weight experiments, conducted at the ordinary temperature for periods of a few months only, give no clue whatever to the behavior of the alloys at 40 degrees C. as regards dezincification. The small losses of weight shown by Muntz metal after dezincification has begun are due mainly to the fact that, though dezincification begins soon and penetrates deeply, yet it is severely localized.

Experiments Carried Out at 50 Degrees C.

Observations made upon the temperature of the outlet water from condensers in practical use showed clearly that much higher temperatures than 40 degrees C. occurred frequently in the interior of the condensers.

It is not very unusual for the outlet water to reach a temperature of 45 degrees C., especially in the case of ships trading in the tropics, and this indicates that at certain points along the interior of the tubes the temperature of the water would be at least 50 degrees C. In view of the results obtained at 40 degrees C., it therefore appeared desirable to examine the effects produced during corrosion at a higher temperature. Accordingly, an electrically heated thermostat was installed to run at 50 degrees C. Beakers of sea water were suspended in the thermostat by means of wooden trays and a pair of 3-inch tube-lengths immersed horizontally in each beaker as before.

The experiments at 50 degrees C. were confined mainly to the 70:30 and 70:29:1 alloys, as the space in the apparatus was more limited than in the case of the thermostat at 40 degrees C.

The 70:30 tubes showed clear signs of dezincification after seven days' immersion; the action began at the edges and ends, and spread later to the backs and interior surfaces of the tubes.

The 70:29:1 tubes were far more resistant than the 70:30, and no signs of dezincification could be detected at the end of six weeks' immersion. In view of the fact that this alloy showed slight dezincification at the end of three weeks at 40 degrees C., this result is remarkable, and it appears to indicate that there is a limited range of temperatures over which dezincification can take place. The matter deserves further investigation.

The layer of oxide formed at this temperature was less uniform than usual and decidedly darker in color than that formed at the lower temperatures. Wherever free access of oxygen was limited by the presence of string, coal or other substances in contact with the tube, a bright red form of cuprous oxide was noticeable, especially in the case of the 70:29:1 alloy.

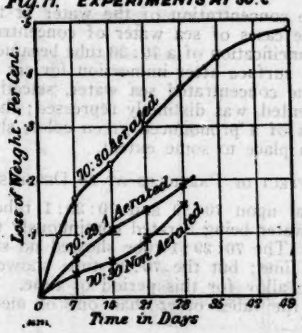
The deposit formed as a result of the corrosion of the 70:30 tubes was in all cases of a dirty white color, very different from the green-blue basic salt formed at lower temperatures. It was found to contain only traces of copper, and consisted almost entirely of basic chloride and carbonate of zinc. The deposit formed from the 70:29:1 tubes was of a pale green color, lighter than that obtained at the ordinary temperature.

It will now be realized that the effect of temperature is of predominating importance in determining the nature of the reaction which takes place when brass is corroded by sea water. At the ordinary temperature both copper and zinc are removed from the metal, approximately in the proportions in which they are present in the brass; and that uniformly over the whole surface of the metal. As the temperature is raised, less and less copper is removed proportionately to the zinc, and at a temperature of 50 degrees C. the attack is concentrated almost entirely on the zinc. The presence of tin in the brass exerts a powerful effect in retarding selective corrosion, as described above. The way in which it exerts this effect is not yet clear, and should be the subject of further investigation.

It will be noticed from the curves in Fig. 11 that the total loss of weight of 70:30 brass at 50 degrees C., is rather smaller than at the ordinary temperature for an equal period of time. It seemed probable that this was due to the decreased solubility of oxygen at the higher temperature. In order to test this a 70:30 and a 70:29:1 tube were immersed side by side in a beaker into which air was pumped continually by a motor-driven force pump, so that the sea water in the beaker was kept continually in a state of violent agitation.

This experiment seemed to the authors particularly important from an entirely different point of view, since it would afford evidence of the effect of the motion of the sea water upon the adherence of the oxychloride to the tube. The results of the experiments as regards loss of weight are given in Table IX and Fig. 11. It will be seen that the speed

Fig. 11. EXPERIMENTS AT 80°C



of corrosion is enhanced by the aeration of the water, and is much in excess of that at the lower temperatures. Moreover, these experiments brought to light the important fact that agitation of the water does not prevent the sticking of the oxychloride to the surface of the tube; rather the selective corrosion seemed to be increased under these conditions and this observation agrees well with the evidence obtained from tubes corroded in practice, in which the oxychloride was found to adhere tightly to the tubes, in spite of the fact that the water is circulated rapidly through them.

TABLE IX.—TESTS AT 50 DEGREES C.

.....	Interval.	Continually aerated.		Not aerated.
		1. 70 : 30	4. 70 : 29 : 1	1. 70 : 30
Initial weight in grammes...	...	21.8007	18.1943	20.9700
Weight after.....	7 days	21.7630	18.1810	20.9562
Loss in grammes.....	...	0.0377	0.0133	0.0138
Percentage loss.....	...	0.17	0.07	0.07
Weight after.....	14 days	21.7446	18.1740	20.9508
Percentage loss.....	...	0.23	0.11	0.09
Weight after.....	21 days	21.7346	18.1680	20.9390
Percentage loss.....	Sea water renewed.	0.30	0.145	0.15
Weight after.....	28 days	21.7182	18.1600	...
Percentage loss.....	...	0.38	0.19	...
Weight after.....	35 days	21.7070	...	...
Percentage loss.....	...	0.43	...	...
Weight after.....	42 days	21.7000	...	...
Percentage loss.....	Sea water renewed.	0.46	...	...
Weight after.....	49 days	21.6965	...	...
Percentage loss.....	...	0 48	...	...

Effect of the Concentration of the Sea Water at 50 Degrees C.

The effect of the concentration of the water at this temperature was only studied for the cases of sea water of concentrations 0.5 and 4. In the former case dezincification of a 70:30 tube became evident at the edges and over the whole surface after immersion for six or seven days.

In the case of the concentrated sea water, selective corrosion, though not altogether prevented, was distinctly repressed; the deposit obtained in this experiment was of a pronounced green color, showing that complete corrosion had taken place to some extent.

Effect of Particles at 50 Degrees C.

The effect of coal upon 70:30 and 70:29:1 tubes was observed for six weeks, the sea water being aerated continuously throughout this time, as described above. The 70:29:1 tube showed no sign of dezincification at the end of this time; but the 70:30 tube showed the usual amount characteristic of the alloy for this period of time. The coal exerted no special effect upon the tubes other than one of mechanical interference with diffusion.

Ferric oxide did not cause dezincification of a 70:29:1 tube in twenty-one days, but appeared to increase slightly the dezincification of 70:30 brass by affording *loci* for the deposition of oxychloride. The effect of graphite and of zinc chloride was similar to that which had been observed at a temperature of 40 degrees C.

The effects of magnesium hydroxide and chloride were also observed, but were found to have no special effect on the type or extent of corrosion.

Section II.

The Experimental Condenser Plant.

In the laboratory experiments hitherto described the principal object kept in view was the investigation of the separate effect of each of a number of the conditions to which a tube might be expected to be subjected in the condenser. In some cases the simultaneous effect of two influences was investigated, as, for instance, those of temperature and deposits, but for the most part the conditions were kept simple.

It seemed very desirable, however, to observe the joint effect of all the influences to which a condenser tube might be subjected under the simplest possible conditions of practice, and to arrange matters in such a way that the nature of these conditions could be ascertained as accurately as possible. It was thought that, with the knowledge of the effect of each condition separately obtained in the laboratory, it might be possible to interpret the results obtained in the more complicated case.

Accordingly, it was decided to erect an experimental plant which should subject forty-eight condenser tubes to conditions approximating as nearly as possible to those obtaining in the ordinary practice of the mercantile marine.

Description of Plant.—The general nature of the required plant was arranged by one of the authors, with the aid of the members of the Corrosion Committee. The engineering details were worked out, and the plant was supplied and erected by Mr. W. W. Strafford, of Great Crosby, Liverpool, and has fulfilled its purpose satisfactorily.

An elevation of the plant is shown in Fig. 12. A is a tubular boiler of special design which works under normal conditions at a steam pressure of 125 pounds per square inch. The steam passes through the pressure gage and throttles shown to the pipe B, and then to the dual-expansion engine C. From the low-pressure cylinder of the engine the exhaust steam passes along pipe D to the four steel cylinders marked E. Each of these cylinders constitutes a separate condenser holding twelve tubes, each 3 feet long. One of these cylinders is shown separately in Fig. 13.

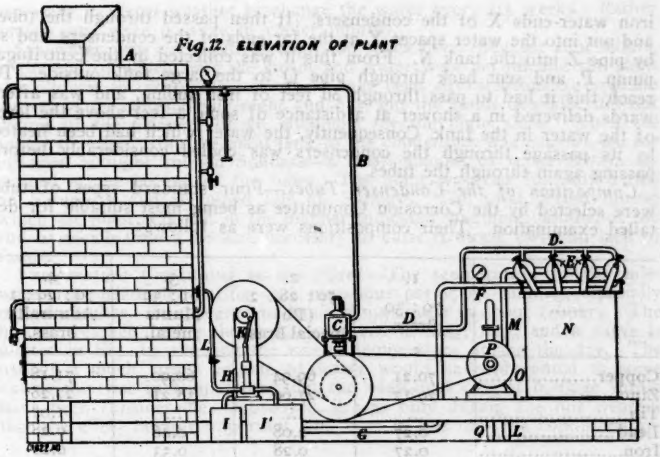


Fig. 12. ELEVATION OF PLANT

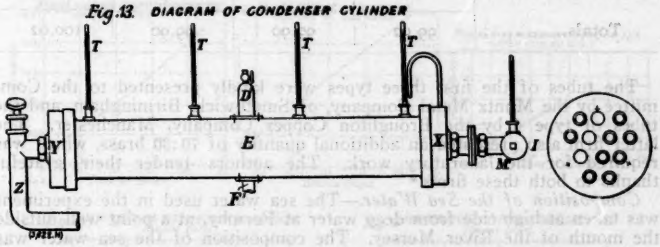


Fig. 13. DIAGRAM OF CONDENSER CYLINDER

The steam from D passes through the control-cocks D (Fig. 13) into the space surrounding the tubes, which are arranged as shown in the elevation of the tube plate in the right part of the figure.

After the condensation of the steam the resulting water leaves the condensers by the pipes F and G, and passes through air pump H, which is hardly visible in the drawing, and reaches the hot well I. From this it was originally picked up by the pump K and returned to the boiler through pipe L and an injector. Later, since oil accumulated in the hot well to some extent, and consequently corrosion of the boiler was feared, the hot water in I was thrown away, and a separate container I′ was used to supply clean water to the boiler.

The circulation of the sea water through the tubes was carried out as follows: A steel tank, which would hold about 600 gallons of sea water, was fixed in the open air outside the building which held the rest of the plant. It was protected from rain, &c., by a cover of galvanized iron raised about 1 foot above the top of the tank on iron supports; the intervening space was covered in by wire netting. Thus air had free access to the tank, but wind-borne rubbish was excluded. The inside surface of the tank was protected by a thin wash of cement.

The sea water from the tank passed by gravity through iron pipes, about 50 feet long, into the room containing the condenser, where it reached the pipes L and M. From these four side tubes M′ led into the four cast-

iron water-ends X of the condensers. It then passed through the tubes and out into the water spaces Y at the far ends of the condensers, and so by pipe Z into the tank N. From this it was collected by the centrifugal pump P, and sent back through pipe Q to the large tank outside. To reach this it had to pass through 50 feet of iron tubing, and was afterwards delivered in a shower at a distance of some 3 feet above the level of the water in the tank. Consequently, the water which had been heated by its passage through the condensers was cooled considerably before passing again through the tubes.

Composition of the Condenser Tubes.—Four standard types of tube were selected by the Corrosion Committee as being most suitable for detailed examination. Their compositions were as follows:

.....	1. 70 : 30 Brass.	2. 70 : 28 : 2 (Pb) Special Brass.	3. 61 : 39 Muntz metal.	4. 70 : 29 : 1 Admiralty brass.
Copper.....	70.21	69.94	60.90	71.18
Zinc.....	29.17	27.60	38.21	27.28
Tin.....	...	...	...	1.07
Lead.....	0.27	2.08	0.46	0.28
Iron.....	0.27	0.28	0.33	0.21
Totals.....	99.92	99.90	99.90	100.02

The tubes of the first three types were kindly presented to the Committee by the Muntz Metal Company, of Smethwick, Birmingham, and the tubes of type 4 by the Broughton Copper Company, Manchester. The latter firm also presented an additional quantity of 70:30 brass, which was required for the laboratory work. The authors tender their grateful thanks to both these firms.*

Composition of the Sea Water.—The sea water used in the experiment was taken at high tide from deep water at Formby, at a point well outside the mouth of the River Mersey. The composition of the sea water was as follows:

	Per Cent.	
Sodium chloride	2.81	Total chloride 3.19 per cent.
Magnesium chloride	0.21	
Potassium chloride	0.17	
Magnesium sulphate	0.11	
Calcium sulphate	0.08	
Calcium carbonate	0.02	

Specific gravity at 17.6 degrees C. = 1.0225.

Owing to the expense of carting large quantities of sea water, it was desirable to use the same sample for as long as possible. Accordingly, the specific gravity and the chlorine content of the water were estimated weekly, so as to afford a guide as to the alteration of the composition of the water with time. Owing to loss by evaporation, both the specific gravity and total chlorine increased slowly in the manner shown by the curves traced in Figs. 14 and 15. It was decided that the total chlorides should not be allowed to exceed 4 per cent.,† and accordingly it became

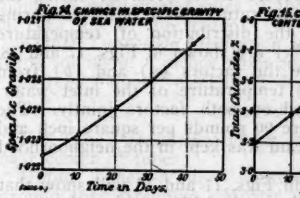
* It should be mentioned that no difference whatever could be detected in the behavior of the 70 : 30 tubes made by these two firms, though they were used side by side in a number of the laboratory experiments.

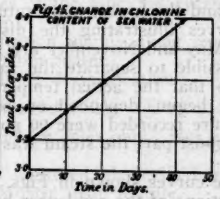
† Laboratory experiments described previously show that a small increase in concentration does not affect the speed of corrosion appreciably.

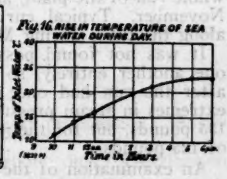
necessary in warm weather to change the water every six weeks. Rather longer runs were possible in cooler months.

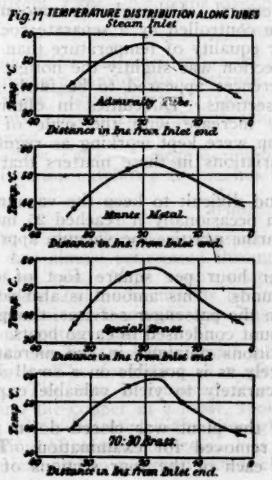
Sea water was circulated through the tubes every day for nine hours, at the end of which time the steam and water were cut off and the plant was allowed to cool down. It would have been advantageous to circulate the sea water continuously night and day, but the funds available did not permit of the payment of an attendant for the night shift. When the supply of water from the main tank to the condensers was cut off—as, for instance, at night and on Sundays—a small amount of water always remained at the bottom of the tubes. The plant was run for half a day on Saturdays and remained idle all Sundays. The total period during which the plant was run in the manner indicated was nine months, at the end of which time it became necessary to close it down, owng to lack of funds.

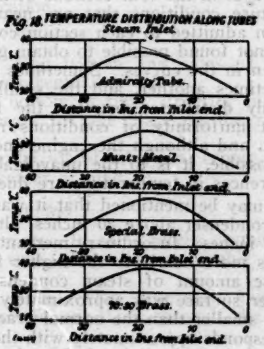
Temperature Conditions in the Plant.—The temperature of the inlet water rose gradually during each nine-hour period of running, especially in hot weather. It appeared to attain a maximum in about 7 hours. The hottest weather during the period occurred in May, 1912, and a curve is plotted in Fig. 16, showing the rise in temperature during the day. The use of a much larger volume of water would have prevented to some extent this rise in temperature, but the additional cost of haulage would have been considerable. Moreover, it was only during the hot weather that the effect became important, and even in this case the conditions ap-











proximated to those which might arise on board a ship trading to the Tropics.

It seemed desirable to obtain a knowledge of the temperatures obtaining in the interior of the condenser, since these could not be deduced from measurements made on the in-going and out-going water. Accordingly, four thermometers were inserted through the casing of each of the four sections of the condenser in such a way that the bulbs of the thermometers were in actual contact with the top tubes. The thermometers were fixed in glands which were made perfectly steamtight. The arrangement is shown at T in Fig. 13.

These thermometers served two purposes—viz:

1. That of enabling four sections of the condenser to be kept at approximately the same temperature by the adjustment of the amount of steam admitted to each.

2. That of indicating the distribution of temperature along each tube.

The actual temperatures observed depended principally upon four factors—(*a*) the atmospheric temperature; (*b*) the amount of steam being condensed; (*c*) the time the plant has been at work; and (*d*) the speed of the water through the tubes. The factor (*d*) was kept constant throughout the whole experiments described in this paper, and its effect will not be considered further. As regards factor (*a*) the plant ran from March, 1912, till the following December, and during this period some of the highest temperatures recorded for the inlet water were obtained during the month of May. No severe frosts occurred during the whole run of the plant, and the lowest temperatures were observed during November. Typical curves illustrating the distribution of temperature along the tubes during May and November are shown in Figs. 17 and 18.

It was not found possible to separate the factors (*a*) and (*b*) from one another entirely, so that the actual temperature of the inlet water, after the run had once begun, depended on both factors jointly. The extremes in steam pressure recorded were 90 pounds per square inch and 135 pounds, but for the most part the steam was kept in the neighborhood of 125 pounds.

An examination of the curves shown in Figs. 17 and 18 will show that the tubes in the four sections of the condenser had been subjected to temperature conditions that are nearly identical. Although the amount of steam admitted to each section could be controlled by a separate cock, it was not found possible to obtain greater equality of temperature than that shown in the curves. Sometimes one section was slightly the hottest and sometimes another, and the small differences appeared to be fairly uniformly distributed between the four sections. Difficulties in obtaining exact uniformity of conditions rapidly increase with the scale of the plant, and although the engine and pump were kept working as regularly as possible, it is to the unavoidable variations in these matters that the differences in temperature are due.

It may be mentioned that it was found difficult to keep the vacuum in the condenser above 20 inches, although occasionally it reached 25 inches to 27 inches. In ordinary mercantile marine practice the vacuum approximates more nearly to the higher figure.

The amount of steam condensed per hour per square foot of condenser surface was approximately 5 pounds. This amount is also somewhat smaller than the normal practice in the passenger services, though it corresponds approximately with the amount condensed in cargo boats. On the whole it is claimed that the conditions obtained in the mercantile marine have been reproduced as accurately as is possible on a small scale plant, and, at any rate, sufficiently accurately to yield valuable experimental results.

At the end of nine months' working the plant was closed down, and three tubes of each composition were removed for examination. They were selected from similar positions in each of the four sections of the

condenser, and the positions are indicated in Fig. 13, where the three blank spaces in the right part of the figure indicate the positions from which the tubes were withdrawn. After removal, the tubes were cut in half longitudinally, so that the interior surfaces might be examined.

Nature of the Scale.—In all cases the tubes were covered with a brown layer, which consisted chiefly of ferric oxide; it contained also sodium chloride and calcium carbonate, as well as traces of sulphate. This layer was loose and easily removed from the tube. Beneath it a rather more adherent layer was found. This was greenish in color, and contained both copper and zinc in the form of basic chloride and carbonate. In places small white spots or particles of zinc oxychloride replaced the green layer, and the tube underlying these areas was found to be dezincified. In case of the Muntz-metal tube the green layer was normally absent and was replaced by a very thin gray-white layer of zinc oxychloride. Beneath the layer of basic salts, a layer of brown or black oxide, strongly adherent to the tube, was found in all cases. In no case were any particles of graphite found amongst the scale. Evidently such particles as result from the dissolution of the cast-iron water-ends are washed away in the stream of sea water.

Results of the Examination of the Tubes.

Admiralty Tubes, 70 : 29 : 1.

Top Tube.—Dezincification in irregularly-shaped spots are areas, mainly along the bottom and sides of the tube, but extending for about 8 inches on each side of the center.

Middle Tube.—Dezincification mainly along one side of the tube. Extends for about 6 inches from center.

Bottom Tube.—No signs of dezincification.

Special Brass, 70 : 28 : 2.

Top Tube.—Dezincification at sides only. Not very pronounced. Mostly near center of tube.

Middle Tube.—A few scattered dezincified spots only. Distribution around tube irregular. Mostly near middle.

Bottom Tube.—No signs of dezincification.

Brass, 70 : 30.

Top Tube.—Dezincification in spots along bottom and sides of tube, extending a considerable distance from the center.

Middle Tube.—In spots, mainly along bottom of tube. Interior surface of tube uneven and dezincification appears to take place on the raised portions.

Bottom Tube.—A large dezincified area at top of tube, near center. Dezincification extends a few inches from center of tube.

Muntz Metal, 61 : 39.

Top Tube.—Severe dezincification in spots. In some places dezincification has almost penetrated through the tube. Especially noticeable along sides of tube. Most severe near center.

Middle Tube.—Numerous dezincified spots. One large area, 2 inches from center. Dezincification has penetrated one-third through the tube in one or two places.

Bottom Tube.—A few small spots at top of tube.

Note.—The formation of a pit appears to take place in the following way. The zinc is removed from certain spots in the tube, and leaves behind the copper in a loose, spongy and rotten form. When dezincification has penetrated right through the tube, and the copper has lost its backing of unaltered brass, it is quickly worn away mechanically. Mechanical, and to a certain extent chemical, action also removes some of the

copper even before dezincification has penetrated right through the tube. This is shown by the measurements of the depths to which the coppery area is depressed below the general level of the surface.

The most important deductions which the authors consider may be drawn from this series of observations are:

1. *The Order in which the Tubes Resist Dezincification.*—The most resistant were the 70:29:1 and the 70:28:2 tubes. These appear to resist the action to about the same extent, and were considerably more resistant than the 70:30 brass, which came next in order of merit. The Muntz-metal tubes were decidedly the most quickly attacked.

2. *The Importance of Temperature in Corrosion Phenomena.*—In all cases the attack appeared to be most severe at or near the centers of the tubes. Since the steam entered the condensers at the center and no baffle-plates were used, the tubes must have been subjected to the highest temperatures at their centers. It becomes evident, therefore, that temperature plays a most important part in determining the distribution of the areas of dezincification.

3. *Corrosion is not Confined to the Bottom of the Tubes.*—It usually occurs in that position, but is by no means confined to it. It frequently occurs along the sides, and occasionally along the tops of the tubes.

4. *Graphite Particles cannot be regarded as a Cause of Dezincification.*—Dezincification can occur independently of the presence of these or any other foreign particles.

Comparison of the Results Obtained in the Laboratory Work and in the Experimental Condenser Plant.

The agreement between the two methods of work is striking. In both, the order in which the tubes resist dezincification at elevated temperatures has been found to be precisely the same. It is unfortunate that no strictly quantitative expression can be obtained to represent the relative merit of the tubes as regards resistance to dezincification. In the case of the experiment with the condenser plant the authors have been obliged to rely upon mere inspection of the tubes. Nevertheless, there can be no doubt that the 70:29:1 and 70:28:2 tubes are more resistant than the 70:30 brass, and this more than the Muntz metal. The plainest evidence is afforded by the fact that one tube of each of the first two alloys completely resisted dezincification, and this indicates their superiority independently of the exact determination of the areas over which dezincification occurs, though, as a matter of fact, the total dezincified areas in these two tubes were considerably smaller than in the case of the others. That the Muntz metal had suffered most severely was amply shown by the fact that dezincification had penetrated more than three-quarters of the way through the topmost tube in several places, and one-third of the way through the middle tube, whereas in all other types of tube dezincification had penetrated much less deeply.

The supreme importance of temperature, which had been clearly indicated by the laboratory work, was amply confirmed by the large scale test. In each of the four sets of three tubes the topmost was the most severely attacked, and a study of the details of the construction of the condenser will show clearly that the top tube must have been the most highly heated of each set. On the other hand, the bottom tubes of each set must have been subjected to a distinctly lower temperature than the others, and as a result the bottom tubes in two cases have not been attacked at all, and in the other two cases the attack is less than that in the case of the higher tubes. Both sets of tests bring out the fact that the locality in which dezincification occurs is not determined by the electrochemical action of carbon or any other foreign particles settling on the tubes. It is due to a chemical action which becomes the more pronounced as the temperature is raised from the ordinary temperature to

50 degrees C., and probably higher, though the Admiralty tube must possibly be excepted from this statement. This action takes place under conditions which exclude the possibility of the settling on the tubes of any substance not derived directly from the tubes themselves.

Dezincification appears to be a phenomenon inherent in alloys of the brass type, and to be more pronounced the higher the percentage of zinc in the alloy. It starts at certain points on the tubes and spreads outwards from them, till, in time, the whole tube would become dezincified.

A distinct relation has been found between the presence of firmly adherent oxychloride and the spots or areas of dezincification. It has been observed in tubes corroded under conditions of practical work, as well as in the experimental condenser test. Direct evidence has been obtained in the laboratory as to the evil effect of this substance. The authors believe it to be both a result and an accelerating cause of dezincification.

Section III.

The Protection of Condenser Tubes.

This subject has been but incompletely studied owing to lack of time, yet one or two interesting observations have been made which seem to be worthy of record here, since to some extent they may serve as a basis for future work.

The methods in use for the protection of condenser tubes are electro-chemical in nature; they depend either on the use of some metal, such as zinc, iron, or aluminum or its alloys, which is electro-positive to brass, and which will consequently set up an electrical current when both are connected together and immersed in sea water; or on the use of a dynamo to pass the current to the brass. In principle the two methods are identical —namely, that of making brass which it is desired to protect, a cathode at which there will be a tendency for the liberation of hydrogen, while oxygen will tend to be set free at the anode. This anode may consist of any of the metals mentioned above. The idea is to concentrate corrosion on the anode, which is sacrificed to protect the cathode.

The metal zinc has been largely employed for anodes, both for the protection of boilers and condensers. In the case of the latter, it is placed in the water ends and is securely bolted to the tube plates. At first sight it would appear to be a more suitable metal than iron, since it is more electro-positive, but in practice this does not prove to be the case. There appear to be two reasons for this. The first is that the zinc gradually becomes covered with a fairly adherent layer of oxide, which itself is electro-negative to brass, and is a poor conductor of electricity. Thus the protective action of the zinc soon ceases, and might even be reversed but for the poor conducting properties of the oxide. The second reason is that the consumption of zinc is found to be very great—far greater than that demanded by the requirements of electro-chemical protection. It seems probable that the zinc is subject to auto-corrosion due to the action of the zinc-oxychloride which adheres to the metal.

For the protection of condensers zinc has been largely replaced by iron, which is not only cheaper but more efficacious. The iron is used generally in the form of slabs, which are placed in the water ends of the condenser, and are attached by bolts to the tube plates.

If any electro-chemical action is to occur, it is obviously necessary to ensure that the connection between the iron slabs and the tube plate be thoroughly satisfactory. It is, of course, possible that the mere presence of iron slabs in the water ends of a condenser might give rise to a certain amount of protection by depriving the water of a large proportion of its oxygen, which will go to form rust. If this be so, no special care need be taken to ensure satisfactory electrical connections. To test this point the following experiments were made:

Three pieces of 70:30 brass tube were taken, together with three pieces of wrought iron. On to one tube and one piece of iron lengths of copper wire were soldered. These were weighed separately; and then the copper wires were connected together, so as to ensure good electrical contact, yet they could be separated again for weighing purposes. The tube and iron were then immersed in a beaker containing 1½ liters of sea water. One of the other pieces of brass tube was weighed, and suspended in another beaker at a depth of 2 inches from the surface. At a distance of ½ inch above it a weighed piece of wrought iron was arranged. Thus there was no electrical connection between the tube and the iron. The other length of tube and iron strip were similarly immersed in a third beaker through which a stream of air was kept bubbling. The air was introduced at the bottom of the beaker. All the beakers were then placed in a thermostat at 50 degrees C. The object of carrying out the experiments at this temperature instead of at the laboratory temperature, was to ascertain whether electro-chemical protection would prevent selective corrosion, which is particularly active at this temperature. At the end of seven and fourteen days all the pieces of metal were weighed, and the results are given in Table X.

TABLE X.—PROTECTION EXPERIMENTS IN SEA WATER AT 50 DEGREES C.

.....	Interval.	Immersed in 1½ liters sea water and electrically connected.		Not connected. Non-aerated.		Not connected. Aerated.	
		Brass and wire.	Iron and wire.	Brass.	Iron.	Brass.	Iron.
Initial weight in grammes.....	...	24.1859	12.8052	21.1220	11.6890	22.3108	10.0216
Weight after.....	7 days	24.1859	12.5200	21.1035	11.5816	22.2740	9.8750
Loss in grammes,	...	...	0.2852	0.0185	0.1074	0.0368	0.1466
Weight after.....	14 days	24.1859	12.3040	21.0910	11.4640	22.2360	9.6570
Total loss in grammes.....	...	...	0.5012	0.0310	0.2250	0.0748	0.3646

It will be seen that the tube which was in electrical contact with the iron was completely protected, since it shows no loss of weight. The surface appeared quite bright and unoxidized, and no sign of pitting could be seen, although experiments described elsewhere in this paper show that it occurs normally in seven days at this temperature. On close examination the protected brass tube was found to be covered with a uniform thin transparent layer of some substance which could only be removed by scraping. The layer was of about the thickness of tissue paper, and proved to consist of calcium carbonate. The rôle of this layer evidently deserves careful consideration in any discussion on the mechanism of protection.

Neither of the other tubes was completely protected by the iron. The general result of the experiments, therefore, confirms the view which is generally held that good electrical connection between the iron and brass is necessary for the protection of the latter. The tube suspended in the aerated beaker showed severe dezincification on the back and sides, while the other tube was slightly attacked at the edges and on a few scattered spots on the back. The attack was somewhat less severe than would have been expected if there had been no iron in the beaker, but the protection afforded by the latter was slight.

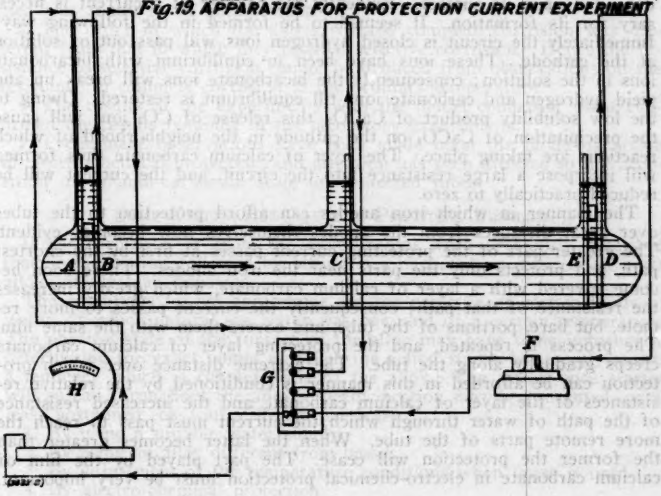
In the experiments just described the iron was arranged close to the brass, so that the conditions were especially favorable for protection. In a condenser containing tubes 16 feet long, on the other hand, the iron slabs, even when used in both water ends must exert a protecting influence over a distance of 8 feet of tube, if the protection is to be effective in the middle of the tube. It seems, at first sight, a little difficult to understand how the protective action of the iron can extend thus far, since, on the electro-chemical view, the protection afforded is proportional to the current passed, and the current passing round the iron-sea-water-brass circuit must be very small, owing to the considerable internal resistance of the circuit. Moreover, it seems as if the greater part of the current would pass through the water to the tube plates, and so back to the iron through the condenser body; only a minute current would pass through the water to the tubes, and so back to the iron *via* the tube plate and body.

The exact amount of current conveyed to any portion of the tube can be readily calculated from the resistance of the sea-water circuit through which the current must pass to reach it. The resistance of this circuit increases rapidly, and at a distance of 8 feet up the tube the amount of current passing to the last few inches of tube must be extremely small. Consequently, it is difficult to see how iron slabs in the water ends can protect the middle of the condenser.

The same difficulty is met with in considering the mode of protection by a current generated by a dynamo, as in the Cumberland process. Of course, in this case a much larger current can be used, and it can be increased at will until it is effective, but the authors have been informed by Mr. Cumberland that in normal cases 2 ampères per 1,000 square feet of tube surface is sufficient for protection, and where such a small average current is used the amount conveyed by the most remote foot of tube will be very small. It seems certain that some other factor must operate to assist protection.

To test the matter the following experiment was made: A glass vessel of the shape shown in Fig. 19 was obtained and filled with sea water. In

Fig. 19. APPARATUS FOR PROTECTION CURRENT EXPERIMENT



it were placed three lengths of 70:30 tube B, C, D, soldered to leads of copper wire, and three of these were connected to a single iron anode, A, and a delicate milliammeter was included in the circuit. The arrangement merely amounts to placing three brass cathodes at three different distances from the anode. These distances were ½ inch, 10 inches, and 20 inches respectively. A fourth piece of tube, E, was placed in the apparatus at the point farthest from the iron, that was insulated from the other piece D and from the iron, and served as a check. It will be noticed that the distance of the farthest tube from the iron anode was forty times as great as that of the nearest. Its area was twice as great, hence the average amount of current conveyed by the farthest cathode was approximately one-twentieth of the current conveyed by the nearest. In an ordinary condenser, if the protector blocks be situated 4 inches from the tube plate and the centers of the tubes be 8 feet away from the tube plate, the last 3 inches of the tube will convey, on an average, one twenty-fourth of the total current, or approximately the same proportion as in the experiment now being described.

At the beginning of the experiment the milliammeter was introduced into the main circuit, thus the total current passing to and from the iron anode could be measured. When the circuit was first closed the indicator needle gave a slight kick and returned to zero and remained there. If the circuit were broken and re-made after a minute or two, the needle again showed a slight kick and returned to zero, and the result could be repeated as often as desired. Evidently polarization prevented any current flowing continually round the circuit.

At the end of three weeks the brass tubes were examined. It was found that each of the three tubes connected with the iron was covered with a thin translucent layer of calcium carbonate. This layer showed a very slight pinkish tinge, due, apparently, to the mechanical entanglement of particles of ferric oxide which permeated the sea water in the apparatus. Underneath the layer the brass was found to be bright and unattacked in all three cases. The piece of brass used as a blank was covered with a layer of brown oxide such as is ordinarily met with in experiments carried out at the ordinary temperature. No layer of calcium carbonate had been deposited upon its surface. Evidently the passage of a current is necessary for its formation. It seemed to be formed in the following way: Immediately the circuit is closed hydrogen ions will pass out of solution at the cathode. These ions have been in equilibrium with bicarbonate ions in the solution; consequently the bicarbonate ions will break up and yield hydrogen and carbonate ions till equilibrium is restored. Owing to the low solubility product of $CaCO_3$, this release of CO_3 ions will cause the precipitation of $CaCO_3$ on the cathode in the neighborhood of which reactions are taking place. The layer of calcium carbonate thus formed will interpose a large resistance into the circuit, and the current will be reduced practically to zero.

The manner in which iron anodes can afford protection to the tubes over great distances from the anodes themselves now becomes evident. The greater part of the protecting current passes at first by the shortest path, and protects only the parts near the iron anodes. These soon become covered with a layer of calcium carbonate, which greatly increases the resistance of that path; consequently the current passes to more remote, but bare, portions of the tube, and covers them with the same film. The process is repeated, and the protecting layer of calcium carbonate creeps gradually along the tube. The extreme distance over which protection can be afforded in this manner is conditioned by the relative resistances of the layer of calcium carbonate and the increased resistance of the path of water through which the current must pass to reach the more remote parts of the tube. When the latter becomes greater than the former the protection will cease. The part played by the film of calcium carbonate in electro-chemical protection must be very important.

It is effective in preventing both the complete and the selective types of corrosion. It even prevents, to a great extent, the initial step towards corrosion—viz: oxidation of the metal. The film appears to be hard, uniform and adherent, and by no means easily broken mechanically. It should be remarked, however, that the experiment in which it was formed was carried out in stagnant sea water—*i.e.*, under conditions in which mechanical injury was not likely to occur. It deserves to be repeated in running sea water. The question may fairly be asked, how can corrosion ever occur when iron slabs or an external current are used for protection? The answer is that it can occur apparently in several ways:

1. By the breakdown in the electrical connections between the slabs and the tube plates, and this may occur by the oxidation of the bolts, nuts, &c.
2. By mechanical injury to the layer of calcium carbonate caused by iron cleaning rods, passage of sharp particles through the tube, &c.
3. By the failure of the calcium carbonate to adhere firmly to the tube, especially if the latter has first undergone slight oxidation and corrosion.

The precise conditions under which this film can be formed and maintained deserve further study.

General Summary of Experimental Work.

All the conclusions tabulated below are based on experiments carried out with natural sea water and ordinary condenser tubes of commerce.

1. The alloys examined corroded in two distinctly different ways, one of which is characteristic of ordinary atmospheric temperatures—termed "complete corrosion"—and the other of temperatures slightly elevated—termed "selective corrosion."
2. Selective corrosion, which results in dezincification and pitting, and is therefore the cause of the practical problem, must be regarded as an inherent property of the alloys examined, provided that sea water and the requisite temperature conditions are present.
3. The influences of a number of the deposits and particles hitherto supposed to be the causes of dezincification have been shown to be unimportant.
4. The influence of the juxtaposition of two phases in the alloys examined was found to be unimportant.
5. The order in which the alloys resisted complete corrosion was different from that in which they resisted selective corrosion. Hence the resistance to selective corrosion cannot be deduced from observations on the resistance to complete corrosion at the ordinary temperature.
6. The results of the experiments with the model condenser plant confirmed the results obtained in the laboratory experiments.
7. Preliminary observations have been made upon the mode of action of electro-chemical protection, and attention has been directed to the deposition of calcium-carbonate scale on protected tubes.

Some Observations on the Practical Problem.

It has become clear from the experimental work previously described that dezincification followed by pitting is a phenomenon inherent in brass alloys of the type discussed.

The conditions for its appearance are the presence of certain kinds of water, of which natural sea water was one, and of a certain temperature. The physical state of the surface of the alloy may have some influence in determining the exact points at which the action starts, but merely assists a tendency which is characteristic of the alloy. The action once started will spread throughout the alloy. Dezincification may be prevented, or at least postponed, by four different methods:

1. By using a suitable water supply.
2. By using an alloy different from brass.
3. By adjustment of the temperature conditions when brass is used.
4. By electro-chemical protection.

In the mercantile marine Method 1 can never be employed, and it can rarely be used even in land installation. Moreover, there is as yet no precise information as to the kinds of water which will not give rise to dezincification. As regards Method 2 very little information is at present available. An obvious suggestion is to lower the amount of zinc present in the alloy, and thus to diminish the tendency towards dezincification. As to how far, if at all, the elimination of zinc could be usefully carried, the authors cannot make any definite statement. It is, however, certain that a complete removal of zinc would give rise to serious trouble of another kind. Possibly there may be some alloy intermediate between 70:30 brass and pure copper which would be more resistable to corrosion than either, though whether it could be satisfactorily drawn into tubes is another matter. Probably manufacturers have already experimented privately along these lines, and information on the subject would be welcomed.

A number of alloys which contain no zinc suggest themselves as suitable for the manufacture of condenser tubes. Phosphor-bronze has been proposed on a number of occasions. It can be drawn into tubes of good quality, and at first sight would appear to be an excellent material for the purpose. Under certain conditions, however, it appears to be subject to a peculiar and deeply penetrating form of complete corrosion, the cause of which has not yet been ascertained by the authors, and the phenomenon of "detinning" has also been observed. More work upon this alloy is desirable before it can be recommended for use. A copper-nickel alloy produced on a large scale in America, and known as "monel metal," has been used for condenser tubes. It appears to give satisfactory results as far as resistance to corrosion is concerned, but its high price has prevented its extended use. The work of Carpenter and Edwards would suggest the use of a copper-aluminum alloy if it could be easily and cheaply drawn into tubes, but the authors have never had an opportunity of experimenting with tubes of such material.

As regards the immediate future, and pending future investigations on different types of alloy, the best means at the disposal of engineers for hindering corrosion appear to be:

1. The entire abandonment of the use of plain 70:30 brass and its replacement by either the Admiralty alloy, 70:29:1 (tin), or Muntz's special brass, 70:28:2 (lead).
2. Careful control of the temperature in condensers.
3. The extended use of electro-chemical protection.

As regards 1, ample evidence will be found in the experimental section of this report, and the matter needs no further emphasis here. As regards 2, the authors consider that the importance of temperature in determining the nature of the corrosive attack on brass by sea water has not received from engineers the attention it deserves.

In practice the most important factor which influences the temperature in a condenser is the amount of steam admitted to it. This may be conveniently stated as the number of pounds of steam condensed per hour per square foot of tube area. Inquiries have been made by the authors as to the average amount condensed in ordinary practice, but they find that engineers are rarely able to state the amount, though they can usually state the amount of steam the condenser was originally constructed to deal with, a somewhat different matter.

In the authors' work with the experimental condenser the temperature of the outlet water rose to 40 degrees C. in hot weather, when only 5 pounds of steam were being condensed per square foot of tube surface. The temperature of the hottest part of the tube rose under the same circumstances to 55 degrees C. Even in cold weather the temperature of the hottest part of the tube approached 40 degrees C., which is in the danger zone. The temperature of the outlet water was then almost 25 degrees C.

The table given before shows that the temperature of the outlet water of ships trading to the Tropics averaged about 42 degrees C., and of other ships about 36 degrees C. It is probable, therefore, that the temperature conditions in the experimental plant were somewhat less severe than in the condensers of ships in the Atlantic and cross-Channel trades. It is particularly noticeable that in case No. 12 of the table, 100 per cent. of the tubes failed in four years, and the temperature of the outlet water was in this case the highest recorded.

In the tables the temperatures of the outlet water vary from 68 degrees F. to 130 degrees F. Part of this variation is, of course, due to variations in the temperature of the intake water, but part is due to conditions which can be controlled. The temperature of the water in a condenser can be kept down in the following ways:

1. By limiting the amount of steam condensed.
2. By shortening the path of the water through the condenser.
3. By increasing the speed of the water.
4. By preventing choking of the tubes, either by fitting screens or filters, or by frequent cleaning.

As regards 1, the amount of steam condensed has been considered hitherto from the point of view of engine efficiency and space economy, and not at all from the corrosion standpoint. Nevertheless, it is a fact that, within the practical limits of temperatures,* the greater the amount of steam condensed the greater will be the tendency to selective corrosion, and if the condenser be really overloaded this form of corrosion may be extremely rapid.

The effect of temperature has been completely masked in recent years because of the peculiar distribution of temperatures in condensers arising from the use of baffle-plates. When these are used the hottest part of a tube is not necessarily the middle of its length, but may be almost any part between the middle and the last foot or two. Its position will be determined by the size of the baffle plates and the velocity of the steam entering the condenser.

The explanation of the extremely long life of the tubes in a Yarmouth trawler, to which reference has already been made, is probably due to the fact that the vessel was normally under easy steaming conditions, and consequently the amount of steam condensed per square foot of tube surface was very small, and the temperature in the condenser low.

As regards 2, the practice of dividing a condenser into two "nests" is a distinct aid to corrosion. As the water passes through the lower nest it becomes heated, and consequently the top nest is supplied with water that it already warm and will become still more highly heated. From the corrosion point of view, it would be preferable to introduce a separate water inlet and outlet to each nest of the condenser, and to discontinue the practice of building them in nests (especially since the condensing efficiency of the tubes in the lower nest is small).

As regards 3, inquiries have shown that the speeds of water through the condensers in the mercantile marine vary between 240 feet and 360 feet per minute. The average for all the figures obtained is about 290 feet per minute. The speed of the water used in the experimental plant was about 275 feet per minute. The faster the speed of the water in the condenser the lower the temperature, other things being equal, and the less the liability to the choking of tubes. In the authors' opinion the speed should be kept up at least to the highest figure mentioned above, and it might be worth while to try still higher speeds.

Inquiries made by the authors have shown that choked tubes are sometimes severely corroded, and sometimes not at all. If a choked tube be found in the bottom part of the condenser working normally it will not

* It is probable that at high temperatures the speed of selective corrosion falls off again, and finally becomes zero, but these temperatures are almost certainly too high for effective steam condensation to take place.

usually be corroded, since its temperature, even in this case, is still low; if, however, the condenser is being overloaded, as shown by the high temperature of the outlet water, it may be severely corroded. If a choked tube be found in the top part, however, it will usually show severe dezincification, owing to the high temperature to which it has been heated. Hitherto the corrosion of choked tubes has been attributed to the electrochemical action of particles, more particularly of carbon, but this view has now been clearly shown to be untenable.—"Engineering."

AIR IN CONDENSERS.

By H. Fothergill.

Synopsis.—*An analysis of the various ways in which air may get into condensers, preventing the maintenance of high vacuums, and suggested remedies.*

While every engineer knows that air in a condenser is antagonistic to a high vacuum and high condensing efficiency, few realize the importace of it. The question of air in a condenser is not so vital to the reciprocating engine, but with the steam turbine, in which advantage is taken of the heat units in the steam at lower pressures, to obtain such low pressure, or more generally called high vacuum, entry of air must be minimized.

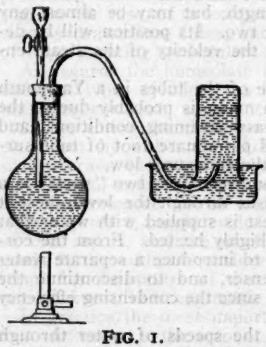


Fig. 1.

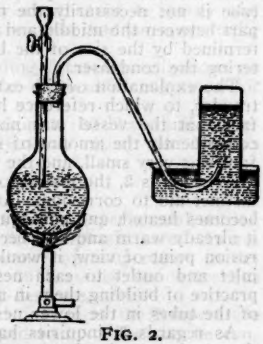


Fig. 2.

Test for Percentage of Air in Water.

To analyze the matter thoroughly it will be necessary to consider separately every way by which air can enter the system and ultimately reach the condenser so as to impair the vacuum. Beginning at the source of steam supply, the amount of air which enters a boiler depends upon the amount in solution in the feed water plus the amount added by the feed pump. The air in solution in the feed water varies considerably and depends upon the nature of the source of the feed makeup, and the means for discharging the water of condensation from the condenser, which latter question will be dealt with later.

Feed makeup water, supplied from fresh-water tanks or water mains, is aërated from approximately 3 to 3½ per cent. of its volume, but it

is easy to test the percentage of air in a feed water. The apparatus necessary, Figs. 1 and 2, consists of a flask connected to an inverted graduated jar, by a pipe, the jar being placed in a vessel in which the water is kept cool by any convenient means. The flask should be entirely filled with the sample of feed water and the glass jar also filled with water, as in Fig. 1; the water in the jar is preferably deaërated. Next heat is applied to the flask, as in Fig. 2, and boiling continued until the bubbles cease to rise, when the jar and beaker should be allowed to cool to the same temperature as at starting before taking any readings. The weight of the feed water from which the air has been driven off should be ascertained before commencing the experiment, so that the volume can be found. The volume of the air driven off is known by measuring the contents occupied by the air in the inverted jar; the percentage of air to the water by volume is equal to the volume of air driven off multiplied by 100, divided by the volume of water.

The amount of air added by a feed pump depends largely on the type of pump employed. With the old-fashioned, continuous-running, single-acting plunger pump, the air passed through a maximum, because the suction pipe of the pump may often be open to the atmosphere. But in modern

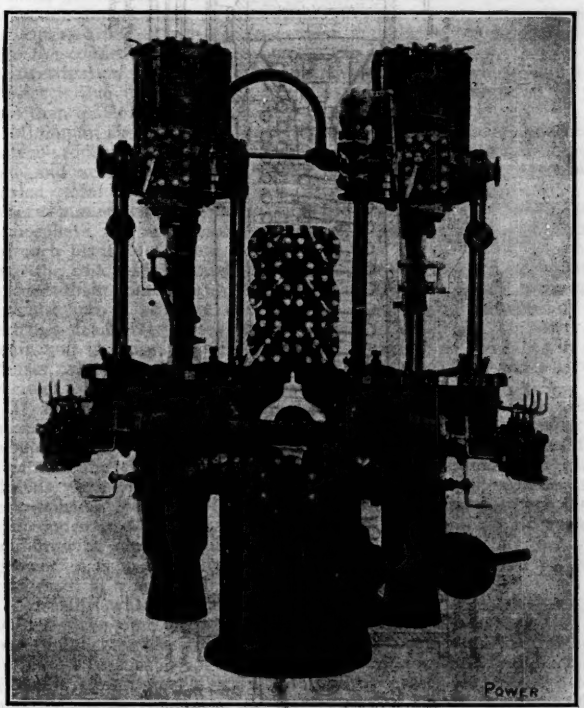


FIG. 3.—FLOAT-CONTROLLED BOILER-FEED PUMP.

feed pumps which are independently driven and have their action float-controlled so that the pump speed corresponds to the quantity of water to be dealt with, the suction inlet to the pump is always under water, and, therefore, the least air passes through, such air as does pass through being in solution in the water. Fig. 3 illustrates a convenient float-controlled boiler-feed pump. The tank from which the water is taken is immediately in front of the pumps and contains the float-controlling gear which is connected to the steam-supply valve by the balanced lever at the right side of the tank and the vertical rod. Whenever the water level in the tank falls below a predetermined limit the steam supply to the pumps is reduced or cut off.

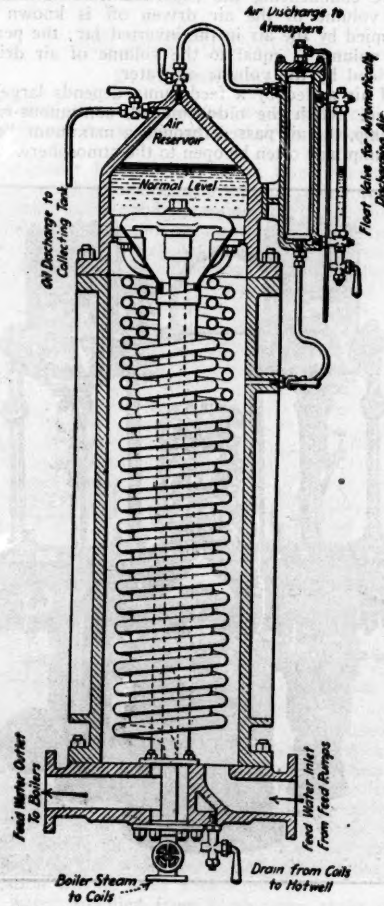

Air Discharge to Atmosphere
Air Reservoir
Normal Level
Oil Discharge to Collecting Tank
Float Valve for Automatically Discharging Air
Feed Water Outlet to Boilers
Feed Water Inlet from Feed Pumps
Boiler Steam to Coils
Drain from Coils to Hotwell

FIG. 4.—SECTIONAL VIEW OF SURFACE FEED HEATER.

As the liberation of air from the feed water is greatest when the water approaches the boiling point, it is desirable that an air-liberating device be combined with a feed-water heater through which the water passes before entering the boilers and thus prevent as far as possible the admission of air with the feed water.

Fig. 4 shows a good combined heater and air extractor in which steam enters the central supporting pipe and, after passing through the distributing chamber, flows down through the double coils. The condensed water from the coils is discharged into a hotwell or feed tank. The feed water is heated by contact with coils of gradually increasing temperature, and finally passes through the central discharging tube where it is in contact with the inlet steam pipe, the surface of which is of maximum temperature. The feed water on its upward course through the heater is rapidly raised in temperature, and on passing through the contracted area at the edge of the inverted cone, its upward velocity is so increased that the air bubbles are carried to the surface of the water in the dome where they are liberated and accumulate until the water level is forced downward enough for the float in the chamber connected to the heater to fall and open the air-discharge valve at the top.

Most generating stations have a float-controlled feed pump, or an air-collecting and discharging feed heater, and sometimes both; so that little air enters a boiler with the feed water and thence passes with the steam into the condenser.

Investigation has shown that nearly all the air which enters a condenser is due to the leakage of joints and glands subjected to pressure less than that of the atmosphere.

Minimum air leakage is experienced when the steam-condensing and power-producing aparatus consists of a steam turbine having tight glands, few and accessible joints, and the connections to the condenser water sealed. Maximum air leakage is usually found in reciprocating engines, where numerous glands are subjected to a pressure lower than the atmosphere, and where auxiliary engines exhaust into the main condenser. In such plants the actual loss of power on the main unit by air leaking into the condenser through the auxiliary engines, is so great that it may exceed their total power, and, therefore, the auxiliary engines should exhaust into a separate condenser at atmospheric pressure or into an exhaust-steam feed-water heater. This possible loss in power on the main unit is caused entirely by the air drowning of the tubes in the condenser, which results in a reduced rate of condensation and a less perfect vacuum.

If a condenser could be had containing no air, the ideal condensing possibilities would be realized and the condensation of steam under vacuum would be very simple, as the heat transfer through the tubes from the steam to the circulating water would be at a maximum for given conditions, thus producing the lowest temperature possible under such circumstances. Moreover, in the absence of air, the temperature throughout the condenser would be approximately the same, and no air pump or air-withdrawing device would be required. However, air being always present, it is necessary to consider how to keep the ratio of air in the condenser at a minimum.

Normally, when a condenser is under load, the air entering and leaving it in a given time is the same; but the ratio of air to steam in different parts of the condenser varies greatly. For instance, at the exhaust-steam inlet of a reasonably air-tight system the air to steam is so small that its effect is almost negligible. As the vapor passes through the condenser and the steam condenses, the percentage of air increases rapidly, until at the air-pump suction the air forms a very considerable proportion of the mixture. The weight of air in a condenser does not depend entirely

on the capacity of the air pump, but to a very large extent on the design of the condenser. The high surface efficiency in all modern condensers is largely due to the absence of idle corners or pockets which would soon fill up with the air hanging around the tubes, as the transfer of heat and rate of condensation in such idle parts would be reduced to a minimum.

Another very important feature, which has only recently been emphasized and brought to the notice of engineers by D. B. Morison, is that the steam passing through the condenser should be so directed and guided that its kinetic energy is utilized in driving the air onward toward the air outlet. This feature, with others, forms the basic principle of the new Contraflo Kinetic Condenser, the patents for which are owned by the Contraflo Condenser & Kinetic Air Pump Co., Ltd., of London. This condenser is of simple construction, as will be seen from Fig. 5, which illustrates a popular design now put forward.

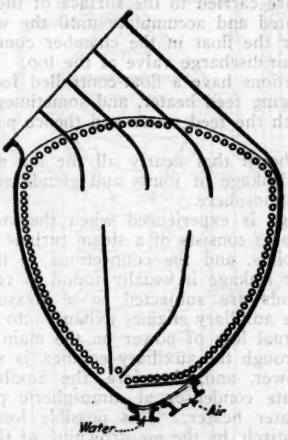


FIG. 5.—CONTRAFLO CONDENSER.

The reasons which prompted this particular design were as follows: Experiment had shown that condensing efficiency is promoted in a surface condenser when the aërated steam is caused to pass over the condensing surface in a continuous current having uniform distribution and uniform direction of flow toward the outlet from the condensing chamber. It was known from previous experience that the insulation effect of the air particles which impinge on the tubes at the steam entry is prejudicial to condensing efficiency, while at the exit the air density may be such as to render the tube surface practically inoperative for condensing vapor. Further, the fact was borne in mind that steam enters a condenser, as, for example, from a steam turbine, at a velocity of about 500 feet per second, and that at this velocity the kinetic energy of flow is considerable. As a consequence it was decided to direct the incoming steam by plates so as to pass over the condensing surface in a direction to promote stream lines of steam flow vertically or obliquely downward toward the air outlet. Thus the eddying of air particles in their passage through the condensing chamber is prevented and the kinetic energy of steam flow is utilized for, as it were, compressing the air into the air outlet and so assisting the air pump to withdraw the air from the condenser.

When water of condensation is withdrawn from a condenser with the air as by an air pump, it becomes highly aërated, but when withdrawn separately, it may be removed in a state of minimum aëration and delivered direct to the feed tank or feed pump.

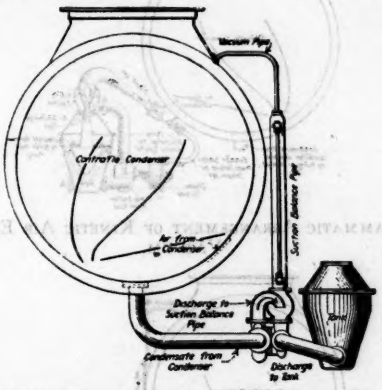


FIG. 6.—DIAGRAMMATIC ARRANGEMENT OF TWO-STAGE PUMP DISCHARGING CONDENSATE TO TANK.

Fig. 6 shows a rotary water-expelling device which is now being largely used in England. The apparatus consists of two pumps, the first or head pump discharging into a receiver that is connected to the second or pressure pump. This receiver is also connected to the condenser so as to provide a free escape for any air that may be carried into the receiver in suspension in the water. It will also be noticed that the discharge from the first pump is in the direction of the suction inlet to the second pump, so that the kinetic energy of the water discharged by the head pump assists its flow into the pressure pump. Before head and pressure pumps were adopted, removing the water from a condenser by a centrifugal pump required placing the pump some distance below the condenser to produce such a head on its suction side as would insure its satisfactory working. In the head-and-pressure-pump system the pumps may be practically on a level with the bottom of the condenser, the first pump producing the artificial head on the suction side of the second pump, thus avoiding need of room below the condenser, which often is not available, especially on shipboard.

While describing this rotary system of water withdrawal reference may be made to the Kinetic air pump with which such excellent results have recently been obtaned. Fig 7 shows the system diagrammatically and Fig. 8 the Kinetic air pump combined with the head and pressure pumps. In Fig. 8 the head and pressure pump *A* driven by the steam turbine, *B*, is removing the water from the condenser. This water—the boiler feed—is delivered into the tank *C*, from which it is withdrawn by the Kinetic pump *D* and is redelivered into the tank through the nozzles at *E*. The arrangement at *E* is the Kinetic ejector and is best seen in section in Fig. 7. Its function is to take hold of the mixture of steam and air coming from the ejector steam jet *F* and pass it into the tank *C*. The supply for the steam jet *F* is the exhaust from the turbine *B*, and as this steam is condensed by the feed water passing through the water ejector *E*, the whole of the heat in the system is conserved in the feed water and can be returned to the boiler.

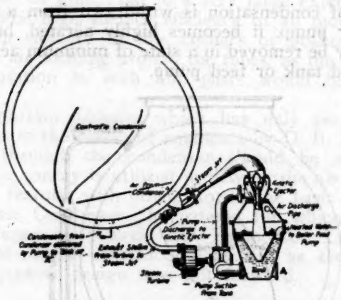


FIG. 7.—DIAGRAMMATIC ARRANGEMENT OF KINETIC AIR EJECTOR FOR HIGH VACUUM.

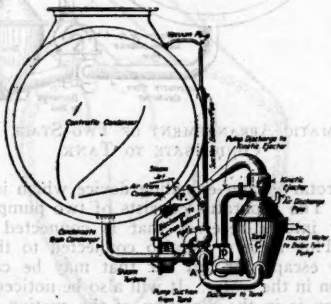


FIG. 8.—DIAGRAMMATIC ARRANGEMENT OF KINETIC SYSTEM.

Several large installations based on the Contraflo Kinetic principles are under construction, including a large plant for Chicago, which has an overload capacity of 25,000 kw.

From the foregoing it will be seen that the question of air in high-vacuum surface condensers is one that must be considered by every engineer, whether he be designing or superintending the running of a steam-condensing plant.—"Power."

THE PREPARATION OF STEEL SECTIONS.

*On a Method of Preparing Sections of Fractures of Steel for Microscopic Examination.**

By ALFRED CAMPION, F.I.C. (Professor of Metallury in the Royal Technical College, Glasgow), and JOHN M. FERGUSON, A.R.T.C. (Glasgow).

In investigations relating to the breakdown of metals under stresses, however they may be applied, it is now recognized that the examination of the fracture, or of a section through the fracture, is often of the greatest importance. In many cases it is necessary to examine a section cut through the fracture of the material, in order to determine the manner in

* Paper submitted to the Iron and Steel Institute at Brussels, September 2, 1913.

FIG. 1.—POLISHED BUT UNETCHED. SHOWING JUNCTIONS BETWEEN STEEL AND ALLOY. MAGNIFIED 150 DIAMETERS.

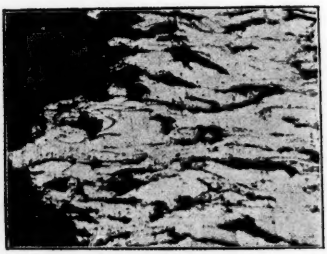


FIG. 2.—SECTION THROUGH TENSILE FRACTURE OF STEEL PLATE TEST PIECE. MAGNIFIED 150 DIAMETERS.

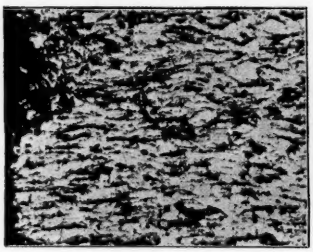


FIG. 3.—SECTION THROUGH FRACTURE OF TENSILE IMPACT TEST PIECE. MAGNIFIED 150 DIAMETERS.

FIG. 4.—SECTION THROUGH FRACTURE OF REPEATED IMPACT (STANTON) TEST PIECE. MAGNIFIED 150 DIAMETERS.

FIG. 5.—SECTION THROUGH FRACTURE OF REPEATED BENDING (SANKEY) TEST PIECE. MAGNIFIED 150 DIAMETERS.

which rupture has taken place, before deciding upon the suitability or otherwise of material for a particular purpose.

As is well known, steel that has shown excellent results as regards tenacity and ductility in an ordinary static test, frequently fails under a load much below the maximum stress, or indeed the yield stress of the metal as shown by the usual tensile test; such material under impact or dynamic stress, breaks suddenly, and appears to be very brittle. In such cases an examination of a section through the fracture often reveals the reason for such apparently extraordinary behavior of the material.

Rosenhain† has shown the importance of a knowledge of the manner in which fracture takes place, in metals and alloys, and its bearing upon engineering and other problems. He has also demonstrated how differently the same material may behave when submitted to variously applied stresses. The preparation of sections of fractures for microscopical examination, especially of soft and ductile materials, presents considerable difficulty, as during the polishing operations the edges of the fracture become more or less rounded or worn away, and the true nature of the fracture is not discernible. In order to overcome this difficulty Rosenhain employed an ingenious method of embedding the fracture in copper, and then cutting through the copper and steel in the desired direction, much in the same way that the biologist embeds his specimens in wax before sectioning. This method of depositing copper (or iron) electrolytically gives excellent results, and is quite satisfactory where comparatively few specimens have to be examined, or where no great hurry is necessary. It requires, however, strict attention to details, and it takes a considerable time to obtain a deposit one-eighth of an inch in thickness. There are many occasions when an examination of a section through a fractured test piece would be of immense value, provided that it could be made easily and quickly.

The authors recently had occasion to examine a very large number of fractures of static and impact tensile and other test pieces. The time at their disposal was, however, too short to allow of their being prepared by the Rosenhain method of electrolytically depositing copper or iron, and they were led to consider the possibility of other methods. It occurred to one of them that it might be possible to cast an easily fusible alloy around the fractured end of the test bar and then section and polish.

The conditions to be satisfied appeared to be—

1. The alloy must be of such a nature that it would readily penetrate into and fill up the minute fissures in the fracture.
2. The alloy must be sufficiently hard and strong to support the edges of the fracture during polishing.
3. The alloy must melt at a low temperature, so that no alteration of the structure of the material would be produced.
4. The alloy must adhere closely and strongly to the specimen, and not be torn away from it during the operations of grinding and polishing.
5. The alloy must exert no chemical or other action on the edges of the specimen.
6. The alloy must be of such a nature that the edges of the fracture would show up sharply and clearly even after fairly strong etching.

Experiments were carried out with a number of alloys, and eventually two were found that fulfilled the above conditions in a marked degree. The composition of the alloys was as follows:

	Alloy A.	Alloy B.
Bismuth	50 parts	50 parts
Lead	30 parts	30 parts
Tin	25 parts	10 parts
Zinc	3 parts	.. parts
Cadmium	.. parts	10 parts

† Journal of the Iron and Steel Institute, 1904; "Engineering," September 9 and 16, 1904.

Both alloys melt at temperatures below the boiling point of water, the melting point of B being about 25 degrees C. less than that of A. As a result of a large number of trials the alloy A was found to be the better for general work. The method adopted in preparing the sections was as follows:

The fractured test piece was dipped momentarily in hydrochloric acid of 1.1 specific gravity, and then in a solution of chloride of zinc (the ordinary "killed spirits" of the tinman) prepared by adding zinc to strong hydrochloric acid until no further action takes place, and then diluting with an equal volume of water. The end of the specimen was then plunged into a quantity of the alloy at such a temperature as just to keep it molten, and contained in a small, deep, narrow mold or crucible. The cold specimen usually somewhat chilled the alloy and caused partial solidification. It was therefore found advisable to remelt the alloy by gently warming the mold or crucible so as to allow of the escape of any air which might have been trapped, and also to ensure perfect adherence between the alloy and the steel. The latter being lighter than the alloy, the specimen must be weighted or held down in the molten alloy to the necessary depth until solidification takes place. When cold, sections may be cut in any desired direction by means of a fine saw. Polishing can then be carried out in the usual manner.

A few micrographs of fractures prepared by this method are given above in order to show the results obtained.

Fig. 1 shows a section of a tensile impact fracture of soft steel embedded in the alloy, polished, but unetched. It shows the junction of steel and alloy. Figs. 2, 3, 4 and 5 are micrographs of etched sections of static tensile, impact tensile, repeated transverse impact (Stanton), and repeated bending (Sankey) test pieces respectively. The magnification is 150 diameters in all cases.

The authors claim no advantage for this method over the Rosenhain method of deposition, except that it is very much quicker. A section may be prepared and a photograph obtained in about thirty minutes. The authors hope that the method may be of interest to those who, like themselves, may wish to examine large numbers of specimens, but whose time is limited.—"Engineering."

DEVELOPMENTS IN BATTLESHIP DESIGN.

The warship *Queen Elizabeth*, which was launched October 16, at Portsmouth Dockyard, is difficult to class, because she has the offensive and defensive qualities of a ship of the line in association with a speed which justifies her classification as a battle cruiser. Indeed, the First Lord of the Admiralty, in referring to her in his program speech in the House of Commons, indicated that the four vessels of the type which are being built will constitute a separate squadron of great power and speed, and from this it is assumed that, in the Admiralty's scheme of strategy and tactics, they will be constituted a battle-cruiser squadron. They are the most powerful ships which have reached the launching stage, and although they are outclassed in size, and possibly also in fighting strength, by ships projected by some other Powers, notably by the United States and France, it remains to be seen whether the designs now under consideration in these countries will materialize. The *Queen Elizabeth* will, when completed, have a displacement, under normal conditions, of 27,500 tons, which is practically 10,000 tons more than the *Dreadnought* of seven years ago; but in America the Navy Board has submitted to Congress proposals for a ship of 38,600 tons, and in France the authorities are preparing plans for a vessel of 32,000 tons. But, as

the American ship is estimated to cost, when completed, £4,144,000, there is room for doubt whether the expenditure of such a large sum of money on one vessel is completely justified. The final estimate of the cost of the *Queen Elizabeth* is not yet available, but there is every probability that it will approximate to 2½ million sterling. It is, at least, significant that the British authorities have not sought for the same high speed in the later ships now being laid down, so that their hull is not so long, and, consequently, there is not the same great expense involved in armor protection. No change, however, is made in the armament or in the effectiveness of the protection for the smaller ship, but the displacement tonnage is reduced to 25,750 tons—a decrease of 1,750 tons.

The *Queen Elizabeth*, it is understood, will steam at 25 knots, which is from two or three miles per hour faster than any existing battleship. The length between perpendiculars has consequently had to be made 600 feet. This is due to the great length of the ship required for the machinery to propel the vessel at the speed named; for, although the boilers are to be worked under oil fuel only, and are consequently to give an increased volume of steam per unit of weight, they still require a very considerable area. Increased length is, of course, also involved in the bigger magazines, to accommodate the projectiles and propellant powders for the large caliber guns fitted. There has been a continuous advance in the displacement of the British capital ships. The *Dreadnought* of 1906 had a length of 490 feet and a displacement of 17,900 tons. This steadily increased until the *Orion* was launched in 1910, of 545 feet long and 22,500 tons displacement. The *King George V*, of the following year, was 10 feet longer and of 500 tons more displacement. The *Marlboroughs*, launched in 1912, were 580 feet in length and of 25,000 tons displacement; and now the *Queen Elizabeth* is 600 feet long, with a displacement of 27,500 tons. The beam has increased in almost the same proportion, and the breadth of the vessel launched yesterday is 90 feet 6 inches. Throughout, however, it has been found necessary to minimize the draught as far as possible; and thus, under normal conditions, the *Queen Elizabeth* draws 28 feet 9 inches, whereas in the earlier ships the draught was between 27 feet and 28½ feet. The ships ordered this year are 580 feet in length, with a displacement of 25,750 tons.

Practically all the Powers have followed us in this increase in the size of ships, and most are building battleships of greater tonnage than the *Queen Elizabeth*, while all seem to desire to outdistance us in size. Thus the vessels being built at the present time for the United States Navy—the *Pennsylvania* class—one of which is building at Newport News and the other at New York Arsenal, will have a length of 600 feet and a displacement of 31,400 tons gross; but the proposal is to make the dimensions of the ship proposed to be laid down this year 750 feet in length, 100 feet in beam, the displacement being 38,600 tons at 28 feet 6 inches draught. The vessel most recently launched for the French Navy, the *Lorraine*, has a length of 546 feet and a displacement of 23,600 tons. The vessels last ordered—those of the *Normandie* class—are 574 feet 3 inches long and of 24,800 tons. There are under consideration at the present time two designs—one for a vessel of 557 feet 9 inches in length, and the other for a vessel of 590 feet 6 inches in length, their respective tonnage displacement being 27,000 and 32,000 metric tons. The latest German battleships in progress are of 27,000 tons displacement, but no information is available as to future intentions. Japan has four vessels in course of construction of 31,500 tons. The new Russian ships now building, two at the Baltic works and two at the Admiralty works, are of 32,000 tons displacement. The most recently completed Italian ships are 550 feet in length and of 19,400 tons, but larger vessels are being laid down. The four Austro-Hungarian ships now being laid down will

closely resemble the British ships of the *Queen Elizabeth* class. It will thus be seen that all the first-class Powers are projecting ships which will considerably exceed the *Queen Elizabeth* in displacement tonnage.

It becomes interesting to examine the offensive power of these respective ships, consequent to their greater tonnage. The *Queen Elizabeth* is the first to be floated of the vessels with 15-inch guns. Of these weapons, eight will be fitted in pairs in four barbettes on the center line, No. 2 turret rising at a higher level than No. 1, and No. 3 to a higher level than No. 4, so that four may fire ahead and four astern, and all may be trained on either broadside. This is the arrangement adopted in all our battle cruisers, and this fact, as well as the high speed, justifies the view that the *Queen Elizabeth* is to used as a ship of this type; but she is much more effectively protected than earlier battle cruisers, the armor being of much greater thickness. Britain led the way also in the adoption of the 13.5-inch gun, and other Powers are following us in their ships now in progress, while some are out-distancing the step taken in the four ships of the *Queen Elizabeth* type. But it is necessary, in making comparison, to consider the length and weight of the projectiles used. Without definite knowledge on this point it would be a mistake to attach too much importance to the caliber of the gun. Another point has reference to the length of the weapons. In some cases the figure given includes the chamber as well as the bore, whereas in the British classification this is not the case. Indeed, it is doubtful if there is much difference in effective energy between the 14-inch and 15-inch guns; but the lower velocity of the latter gun, for a given striking energy, conduces to longer life, while the larger diameter shell assists towards destruction after perforation. We continue to adopt the double-gun barbette system, and this is also the case with Japan and Germany, while Russia, the United States, Italy and Austria-Hungary are fitting triple-gun turrets, although the last-named are reverting to two-gun turrets in their later vessels, and France is introducing four-gun turrets in her newer ships. The objection taken to fitting three or four guns in each barbette is the concentration in a short length of the ship of so much of its offensive power, as it is more liable to be disabled. Against this, there is gain in weight and also in the reduction of the length of the ship for a given fighting efficiency.

In the ships now in progress for the United States Navy twelve guns of 14-inch bore are being fitted. In this case the four barbettes will each have three guns, and the position of these will correspond to those in the *Queen Elizabeth*. The United States authorities in the 38,600-ton ships, now under consideration, propose to adopt the same arrangement of turrets, each with three guns of 14-inch bore. The French authorities are fitting in the *Normandie* class twelve 13.4-inch guns, but in this case there will be three turrets each with four guns. All of these are in the center line of the ship. The central turret is amidships and the guns cannot be used for direct ahead or astern fire, although they have a wide arc of training. It is now proposed, in the new designs to which we have already referred, to fit 15-inch guns, also four in each barbette. In the 27,500-ton ship there will be two such turrets, and in the 32,000-ton ships three such turrets, the number of guns respectively being eight and twelve. The Japanese are fitting twelve guns of 14-inch caliber in the ships now in progress. The Austro-Hungarians, in the ships which have recently been passed into commission, adopt twelve guns in four turrets, with three guns each, disposed as in the *Queen Elizabeth;* but in their later ships they are adopting the *Queen Elizabeth* arrangement with eight guns of 15-inch caliber. The Italian ships having a displacement of 19,400 tons, now being put into commission, have twelve 12-inch guns in four turrets, each with three guns. They are all in the center line, but are arranged somewhat after the design of our earlier battle cruisers,

one triple-gun turret being forward and one aft, with two in the center line amidships, to fire on either broadside, and with a considerable degree of training before and abaft the beam on the port and starboard sides. In the later ships, however, the Italians are fitting 15-inch guns, and it is understood that twelve of these will be fitted in triple-gun turrets. The Russians have also adopted the three-gun turrets in the ships which are now in an advanced stage of construction, twelve of these being arranged for, all in the center line; but in this case the guns are so disposed that only three can fire ahead and three astern, the turrets amidships being capable of discharging on either broadside, with a considerable degree of training before and abaft the beam, although the funnels and superstructure of the ship prevent them firing both ahead and astern. In their new 32,000-ton ships there will be nine 14-inch guns in triple-gun turrets. In the latest German ships the 15-inch gun is also adopted, but, so far as we are able to learn only eight of these are being installed, and the arrangement corresponds with that in the *Queen Elizabeth*.

As regards the lighter guns, it is noticeable that the 6-inch gun or its equivalent, is now almost entirely accepted, and is being fitted in casemates; the difference is only in the number fitted. In the immense ship proposed for the American Navy, twenty-one 6-inch weapons are suggested; in the newer French ships, twenty-four of 5.5-inch bore; in the Austro-Hungarian ships, sixteen of 5.9-inch caliber; in the Japanese ships, sixteen of 6-inch caliber; in the Russian ships, now nearing completion, twenty of 4.7-inch caliber, but in the later vessels the larger gun is being adopted; and in the German ships there are sixteen 5.9-inch guns.

With the increase in the caliber of guns there is a disposition to add to the thickness of the armor on the water line, and now plates of 12 inches or 13 inches thickness are quite common for a considerable depth of the hull, while above this there is 9-inch armor, reduced to 6 inches at the extreme ends on the water line. That is the arrangement adopted in the *Queen Elizabeth*, which is undoubtedly the most effectively protected ship so far built. The Americans, in the proposed 38,600-ton vessel, contemplate the fitting of a belt of maximum thickness of 17 inches, reduced to 9 inches forward and aft, while the barbette armor is to be of 16 inches, and the front plates of the gun-hoods 18 inches, and the side plates 9 inches and 10 inches. In this it will therefore be recognized that they have moved forward from the proposals embodied in the *Queen Elizabeth*, but their advance in this respect, as in others, will be severely criticised by many naval writers on the plea that the advantage may not justify the great cost.

There is a great variety of opinion as to the most effective speed for ships of the line. The *Queen Elizabeth*, as we have said, is expected to attain a speed of 25 knots, which, it is contended by some, is too great for a battleship; but, as Mr. Churchill has already made clear, the four vessels of the class are intended to form an independent squadron with special functions in the Admiralty scheme of strategy and tactics. Without knowledge of these duties it is not possible to give a definite opinion as to whether this high speed is justified in association with the great armor protection to which we have already referred. The battle cruisers of the *Lion* class, of which four have now been built, are of 28 knots speed, and in their case this result involved some sacrifice in armor. Italian naval constructors have always been in favor of high speed, and in their newer battleships the rate anticipated is 25 knots, as compared with the designed speed of 23 knots in the vessels of the *Dante Alighieri* class, which were recently completed. The French authorities, on the other hand, are satisfied with very much less speed, the designed power of the vessel launched a few weeks ago being 19 knots, as compared with 21 knots in the vessels now being laid down. Austria-Hungary, like Italy,

anticipates a speed of 25 knots in the four ships just begun. The Germans are satisfied with 21 knots, so far as ships already ordered afford clear indication of their views on this question.

In all cases turbines have been adopted for propulsion, and in the majority of instances these are of the Parsons type, but in some the Curtis turbine is being fitted. This applies notably to the *Pennsylvania*, which will have Curtis turbines and helical gearing. It is a notable fact, further, that in the latest ship for the American Navy Parsons turbines are being built at the New York Arsenal, the United States Navy having become licensees for this system, and having acquired the machinery for the construction of the turbines. The *Queen Elizabeth* will have Parsons turbines, which have been manufactured by the Wallsend Slipway and Engineering Company, Limited, Wallsend-on-Tyne. As in all our battleships, the turbines will work on four shafts, each of which has an ahead and an astern turbine, the low-pressure ahead turbines being mounted on the inner shafts, and the high-pressure on the wing shafts. For cruising there are two turbines, working through gearing at the forward end of the inner shafts, and arranged to exhaust through the main high-pressure and low-pressure turbines, thence to the condensers. This arrangement will give a satisfactory economy throughout a great range of speed, as it is possible to drive the ship at low speeds with the cruising geared turbines, while the main high-pressure turbine can be brought into action to take the boiler steam at any stage; the valves are arranged accordingly.—"Engineering."

ELECTRICALLY-DRIVEN CARGO VESSEL *TYNEMOUNT*.

By Frederick C. Coleman.

The *Tynemount*, an electrically-driven cargo vessel, recently built by Swan, Hunter & Wigham Richardson, Ltd., of Wallsend-on-Tyne, England, to the order of the Electric Marine Propulsion Co., Ltd., Montreal, and for service on the Great Lakes and canals of North America.

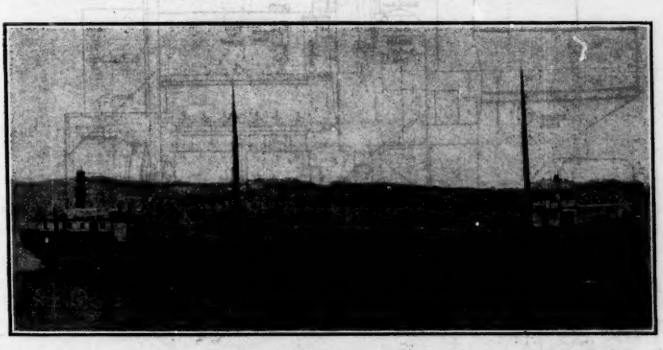
The *Tynemount* is 250 feet in length by 42 feet 6 inches beam, and 19 feet depth molded, and she is adapted to carry 2,400 tons of cargo. The vessel has two masts, forecastle and navigating bridge forward, and poop aft. There are one steel deck and three cargo holds, with seven large hatches. On the deck are steam winches for working the cargo with three 3-ton derricks.

The deck machinery consists of steam windlass, steam-steering gear, and the three steam winches for working cargo and warping. Electric light is fitted throughout. This auxiliary machine is supplied with steam from two Cochran donkey boilers placed in the poop and fired by means of oil fuel. The vessel has a double bottom throughout, with heavy flush-fitted tank-top plating; under the cargo holds the double bottom is adapted for carrying water ballast, as is the forepeak, whilst the tank under the engine room and the after peak may be used for oil fuel. There are also two tanks for oil fuel on the deck forward of the poop bulkhead. In the forecastle is the accommodation for the officers, crew and oilers, whilst above are the captain's sleeping room and his office, together with wheel-house, etc. In the poop are the rooms for the engineers, the galley, the dining saloon and the crew's mess room.

Among other special features may be mentioned a strong oak fender along the sides of the vessel and forward for protection in the locks, a strong oak quarter badging round the stern, "wrecking wells," *i. e.*,

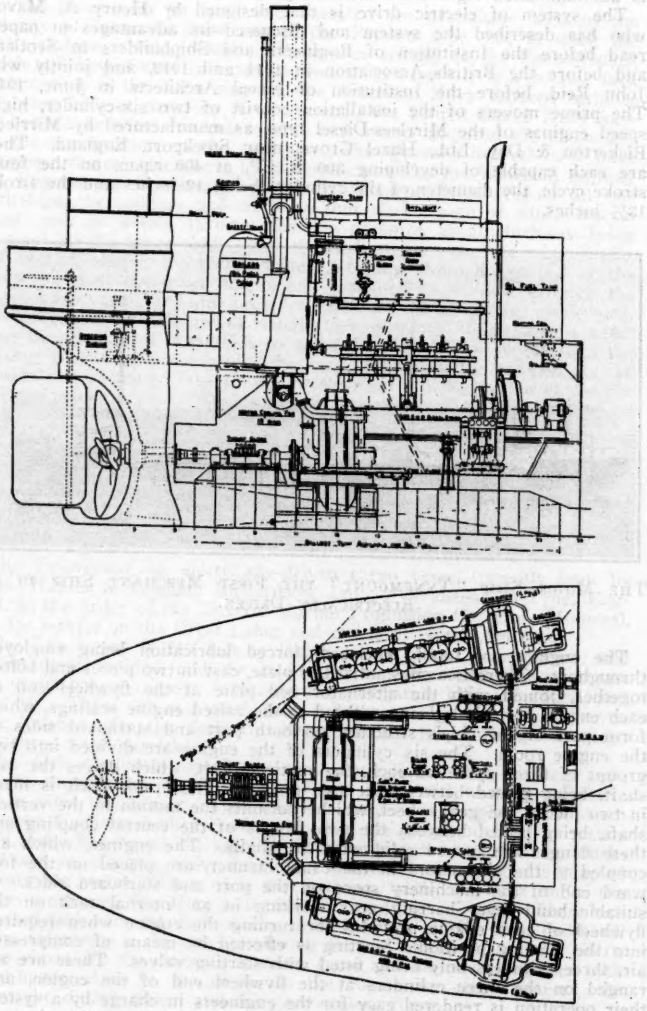
vertical trunks to give access from the deck to the double bottom when the holds are full of cargo, bowsprit for steering, etc. The machinery is accommodated right aft under the poop.

The system of electric drive is that designed by Henry A. Mavor, who has described the system and discussed its advantages in papers read before the Institution of Engineers and Shipbuilders in Scotland and before the British Association in 1911 and 1912, and jointly with John Reid, before the Institution of Naval Architects in June, 1913. The prime movers of the installation consist of two six-cylinder, high-speed engines of the Mirrlees-Diesel type, as manufactured by Mirrlees, Bickerton & Day, Ltd., Hazel Grove, near Stockport, England. They are each capable of developing 300 B.H.P. at 400 r.p.m. on the four-stroke cycle, the diameter of the cylinders being 12 inches and the stroke 13½ inches.

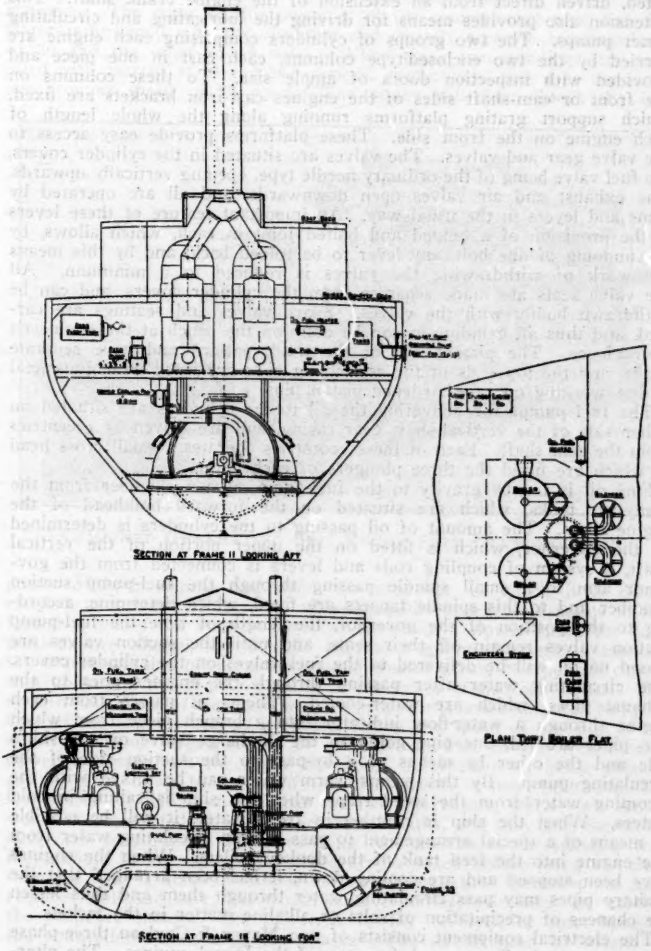


THE MOTOR SHIP "TYNEMOUNT," THE FIRST MERCHANT SHIP TO BE ELECTRICALLY DRIVEN.

The engines are totally enclosed, forced lubrication being employed throughout. There is a substantial bed plate, cast in two pieces and bolted together, joined with the alternator bed plate at the flywheel end of each engine, the whole being secured to the raised engine seatings, which form part of the ship's structure on both port and starboard sides of the engine room. The six cylinders of the engine are divided into two groups of three cylinders each, the vertical shaft, which drives the cam shaft, being placed between the two groups. The crank shaft is made in two pieces, the gear wheel, which transmits the motion to the vertical shaft, being bolted between the two flanges of the central coupling and these flanges are turned solid with the shafts. The engines, which are coupled to the alternators in the usual manner, are placed on the forward end of the machinery space on the port and starboard sides. A suitable hand lever barring gear working in an internal rack on the flywheel of each engine provides for turning the engine when required into the starting position. Starting is effected by means of compressed air, three cylinders only being fitted with starting valves. These are arranged on the three cylinders at the flywheel end of the engine, and their operation is rendered easy for the engineers in charge by a system of bell-crank levers and coupling rods transmitting the motion from a control pillar placed on the engine-room floor in close proximity to the air receivers of the engines. A device for stopping the engine and



ARRANGEMENT OF MAIN AND AUXILIARY



MACHINERY, MOTOR SHIP "TYNEMOUNT."

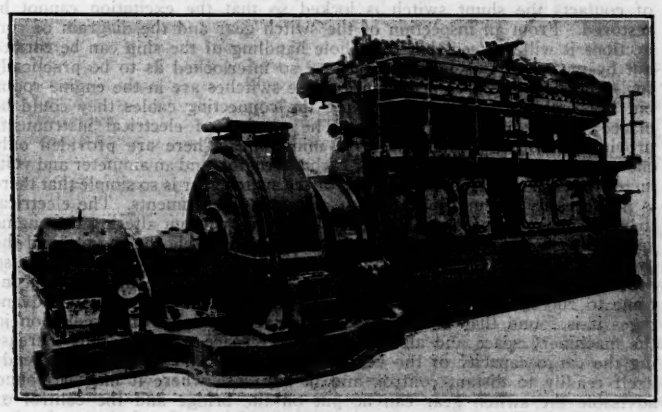
means of controlling the amount of air delivered by the air compressor are also provided on the same control pillar. Near at hand is the electric controller of the transmission system, the whole providing a compact and centralized arrangement for the operation of the propelling machinery. At the after end of each engine a three-stage air compressor is fitted, driven direct from an extension of the engine crank shaft. This extension also provides means for driving the lubricating and circulating water pumps. The two groups of cylinders comprising each engine are carried by the two enclosed-type columns, each cast in one piece and provided with inspection doors of ample size. To these columns on the front or cam-shaft sides of the engines cast-iron brackets are fixed, which support grating platforms running along the whole length of each engine on the front side. These platforms provide easy access to the valve gear and valves. The valves are situated in the cylinder covers, the fuel valve being of the ordinary needle type, opening vertically upwards. The exhaust and air valves open downwards, and all are operated by cams and levers in the usual way. An important feature of these levers is the provision of a hinged and bolted joint in each, which allows, by the undoing of one bolt, any lever to be folded back, and by this means the work of withdrawing the valves is reduced to a minimum. All the valve seats are made separate from the cylinder covers, and can be withdrawn bodily with the valves. Spare valves and seatings are carried, and thus all grinding-in can be done on the bench at the engineer's convenience. The pistons are of the truck pattern and have separate heads, and the top ends of the connecting rods are fitted with gun-metal bushes working on case-hardened piston pins.

The fuel pumps for delivering the oil to the cylinders are situated on either side of the vertical-shaft gear casing, and are driven by eccentrics from the cam shaft. Each of these eccentrics operates a small cross head to which are fitted the three plungers of each pump.

Fuel oil is fed by gravity to the fuel-pump suction chamber from the ready-use tanks, which are situated on the forward bulkhead of the engine room. The amount of oil passing to the cylinders is determined by the governor, which is fitted on the upper portion of the vertical shaft, a system of coupling rods and levers is connected from the governor arm to a small spindle passing through the fuel-pump suction chamber and to this spindle tappets are fixed, which determine, according to the position of the governor, the length of time the fuel-pump suction valves remain off their seats, and until the suction valves are closed no oil will be delivered to the fuel valves on the cylinder covers. The circulating water after passing through the engines goes to the exhaust pipes, which are water-cooled. Thence it passes from each engine through a water-flow indicator into a branch piece from which two pipes are led, one pipe going to the discharge valve on the ship's side and the other by means of a by-pass to the suction side of the circulating pump. By this means warm water can be mixed with the incoming water from the weed traps when the ship is sailing in cold waters. When the ship is running in fresh water, it will be possible by means of a special arrangement to pass the hot circulating water from one engine into the feed tank of the donkey boilers. When the engines have been stopped and are cooling down, it has been arranged that the sanitary pipes may pass circulating water through them and thus lessen the chances of precipitation of salts or alkaline matter in the jackets.

The electrical equipment consists of two Mavor & Coulson three-phase alternators, each direct coupled to one of the Diesel engines. The alternators, when running at their normal speed of 400 r.p.m., each give an output of 500 volts and 270 ampères per phase, which absorbs the full power of the engine. They are provided with six and eight poles, re-

spectively, making the frequency of the current 20 periods per second and 26.6 periods per second, respectively. An exciter is direct coupled to each alternator and is capable of giving an exciting current of 30 ampères for ample working, which can be increased up to 50 ampères whilst maneuvering. The current from these two generating sets is led to a 500-B.H.P. Mavor & Coulson patent induction motor of special construction. The rotor of this motor is of the squirrel-cage type, but the stator is provided with two different and entirely separate windings, one of 30 and the other of 40 poles. When these two windings are supplied with current at 20 and 26.6 periods, respectively, they give the same synchronous speed of 80 r.p.m. The motor will then absorb the full



COMBINED GENERATING SET, MOTOR SHIP "TYNEMOUNT."

power of both engines and drive the propeller, to which it is direct coupled, at a speed of 78 r.p.m. This propeller speed corresponds to the fastest speed of the vessel. In order to obtain a slower speed the connections are altered so that the alternator giving 20 periods supplies the 40-pole-winding of the motor; the alternator giving 26.6 periods can be shut down and the 30-pole-winding of the motor is also out of use. The synchronous speed of the motor with the propeller is now reduced to 60 r.p.m. One of the engines only is available, but as the speed of the ship is reduced to about three-quarters of the normal, half of the total horsepower is ample and the great advantage is obtained of being able to entirely shut down that part of the plant which is not required at the low speed. It will be noted that the two alternators, when both are at work, are connected to entirely separate circuits, and they are, therefore, never run in parallel. The paralleling two alternators necessitating that they should be run up to speed and synchronized before being switched onto the load is quite unsuitable for ship work; this operation not only requires skill and care, but would involve considerable delay in starting the propeller motor. The motor is readily reversed by interchanging the connections of two of the phases. The switch gear, by means of which the necessary changes are made, is extremely simple; it consists of two parts—a main switch of the tramway controller type, having five different positions, full ahead, half ahead, stop, half astern, full astern; and of a second switch, the purpose of which is to introduce resistance

into the shunt circuit of the exciter. The contacts of both switches work under oil, but it is inadvisable that the contacts of the main switch should be required to break the large main current flowing to the motor. The two switches are, therefore, interlocked so that it is impossible to work the main switch except when all the resistance has been introduced into the exciter field coils. There is then practically no excitation and the whole system is dead. With the resistance in the exciter field circuit, the main switch can be moved to any one of its four working positions, and when the main connections have been made for the new running position, the shunt-switch lever is pulled over so as to cut out the resistance and restore the excitation. Until the main switch is definitely on one set of contacts the shunt switch is locked so that the excitation cannot be restored. From an inspection of the switch gear and the diagram of connections it will be seen that the whole handling of the ship can be carried out by means of two levers which are so interlocked as to be practically fool-proof. In the present instance, these switches are in the engine room, but it is evident that by lengthening the connecting cables they could be placed on the navigating bridge. The number of electrical instruments provided has been kept down to a minimum. There are provided only one ammeter, and one voltmeter for each alternator, and an ammeter and voltmeter for each exciter. The handling of the switch gear is so simple that there is no necessity for multiplication of measuring instruments. The electrical drive permits the speed of the ship to be altered without altering the engine speed. It also permits a convenient gear ratio to enable the engines and the propeller, respectively, to be run at their most efficient speeds and also provides for the steady reversal of the propeller while the engines continue to run in their normal direction. In addition to the above advantages it is found that in many cases the system allows of a reduction in the machinery space and also in the bunker space required, thus increasing the cargo capacity of the vessel. As a subsidiary advantage, it lends itself readily to distant control, and in any case where it may be found advisable the switch gear can be put on the bridge and the control of the motor driving the propeller be put into the hands of the navigating officer.—"The Marine Review."

SHIPS.

UNITED STATES.

The following was the total degree of completion of vessels under construction for the U. S. Navy on November 1, 1913:

No.			
	BATTLESHIPS:		
34	*New York*	New York Navy Yard	92.0
35	*Texas*	Newport News Ship Building Co.	96.0
36	*Nevada*	Fore River Shipbuilding Co.	49.2
37	*Oklahoma*	New York Ship Building Co	48.7
38	*Pennsylvania*	Newport News Ship Building Co.	11.8
39		New York Navy Yard	0.0
	DESTROYERS:		
45	*Downes*	New York Ship Building Co	81.7
47	*Aylwin*	Wm. Cramp & Sons	97.4
48	*Parker*	Wm. Cramp & Sons	95.2
49	*Benham*	Wm. Cramp & Sons	93.0
50	*Balch*	Wm. Cramp & Sons	92.6
51	*O'Brien*	Wm. Cramp & Sons	14.9
52	*Nicholson*	Wm. Cramp & Sons	13.6
53	*Winslow*	Wm. Cramp & Sons	14.2
54	*McDougal*	Bath Iron Works	34.3
55	*Cushing*	Fore River Shipbuilding Co.	21.3
56	*Ericsson*	New York Ship Building Co	15.1
	DESTROYER TENDERS:		
2	*Melville*	New York Ship Building Co	10.0
	SUBMARINES:		
26	*G*-4	American Laurenti Co. (Phila.)	96.4
27	*G*-2	Lake T. B. Co. (Bridgeport)	89.7
28	*H*-1	Electric Boat Co. (San Francisco)	97.9
29	*H*-2	Electric Boat Co. (San Francisco)	97.9
30	*H*-3	Electric Boat Co. (Seattle)	98.0
31	*G*-3	Lake T. B. Co. (Bridgeport)	74.2
32	*K*-1	Electric Boat Co. (Quincy)	94.0
33	*K*-2	Electric Boat Co. (Quincy)	91.8
34	*K*-3	Electric Boat Co. (San Francisco)	88.6
35	*K*-4	Electric Boat Co. (Seattle)	88.0
36	*K*-5	Electric Boat Co. (Quincy)	79.3
37	*K*-6	Electric Boat Co. (Quincy)	78.3
38	*K*-7	Electric Boat Co. (San Francisco)	78.5
39	*K*-8	Electric Boat Co. (San Francisco)	76.4
40	*L*-1	Electric Boat Co. (Quincy)	13.0
41	*L*-2	Electric Boat Co. (Quincy)	13.0
42	*L*-3	Electric Boat Co. (Quincy)	13.0
43	*L*-4	Electric Boat Co. (Quincy)	13.0
44	*L*-5	Lake T. B. Co. (Bridgeport)	7.4
45	*L*-6	Lake T. B. Co. (Long Beach, Cal.)	0.0
46	*L*-7	Lake T. B. Co. (Long Beach, Cal.)	0.0
47	*M*-1	Electric Boat Co. (Quincy)	9.7

No.			
SUBMARINE TENDERS:			
1	*Fulton*	New London S. & E. B. Co. (Quincy)	23.4
2	*Bushnell*	Seattle Construction and D. D. Co.	3.0
FUEL SHIPS:			
13	*Kanawha*	Mare Island Navy Yard	9.4
14	*Maumee*	Mare Island Navy Yard	5.3
GUN BOATS:			
19	*Sacramento*	Wm. Cramp & Sons	54.4
20	*Monocacy*	Mare Island Navy Yard	99.0
16	*Palos*	Mare Island Navy Yard	100.0

SUPPLY AND TRANSPORT SHIPS.

The final step in the completion of the design of the supply ship and and transport, at present known respectively as *Supply Ship No. 1* and *Transport No. 1*, provided for in the naval appropriation bill, approved March 4, 1913, was accomplished when Secretary of the Navy Daniels signed and issued a circular inviting all shipbuilders, who have sufficent plant with which to construct these vessels, to submit competitive bids for their construction to be opened Dec. 20. These vessels will be the first of their type designed exclusively for their respective uses up to the present time.

The transport will be 460 feet long, 61 feet beam and 20 feet draught. She will have a maintained sea speed of 14 knots, and will be fitted to provide comfortable quarters for approximately 2,000 men, including about 100 officers. Stables will be provided for 32 horses. Large cargo holds will be fitted for transporting equipment and outfit for establishing an advance base for military operations, in case necessity should require.

The vessel is of the three-deck type, with a large and commodious superstructure amidships, and a deck house aft. The after house contains hospital spaces, which are necessarily extensive for this number of men. The superstructure contains the galleys, bakery and other messing spaces on the main deck, while on the higher levels are the staterooms, messrooms, bathrooms, etc., of the officers of the ship and the troops. The troops and crew are quartered on the troop or second deck.

Special consideration has been given to the boat outfit in order that ample seating capacity may be provided for every person on board. Motor boats and steamers for the towing of life boats have been provided. One of the steamers will be fitted with a wireless apparatus for communicating with the approaching vessels, in case of disaster. The lifeboats proper are of the folding type. Provision has been made for hoisting and lowering them by geared davits, and especial precautions have been taken to insure safety in launching. The large steamers will be handled by the vessel's booms.

The transport will be fitted to burn either oil or coal. She will be equipped with eight 5-inch guns, will have double-bottom protection throughout her entire length and up the sides abreast the engine and fire-rooms. She will be equipped with modern high-power wireless apparatus, searchlights, signal apparatus and facilities for the rapid handling of cargo.

The supply ship will be 400 feet long, 55 feet beam, and 21 feet draught. She will be fitted with cold-storage spaces for the transportation of refrigerated meats, cooled vegetables and a large quantity of ice. This ship is designed to accompany a fleet of eight battleships, and to supply them with provisions for a period of two months.

She will be equipped to burn either coal or oil, will have a high-power radio outfit, four searchlights, and facilities for the rapid handling of cargo. She will be provided with a towing engine for use in aiding disabled vessels of the fleet. Provisions will be made for the transferring, by her own pumps, of fuel oil from her tanks to those of other vessels.

On these vessels especial consideration has been given to the living quarters provided for both crew and officers, in order that all possible facilities and comforts for the personnel, that are compatible with the conditions to be met, may be provided. The ships have been designed with high freeboard and stability such as to make them comfortable and sea-worthy.—"The Marine Review."

U. S. S. *DUNCAN*.

The preliminary trials of torpedo-boat destroyer No. 46, the *Duncan*, were successfully run July 5th to 8th, 1913, inclusive. An average speed of 29.143 knots per hour was attained on the four-hour full-power trial, with the main turbines developing 14,254 S.H.P., at 571.33 r.p.m.

U. S. S. *TEXAS*.

U. S. battleship No. 35, the *Texas*, satisfactorily completed her preliminary trials October 23d to 31st, 1913, inclusive. An average speed of 21.05 knots per hour was attained on the four-hour full-power trial, with the main engines developing 28,373 I.H.P., at 124.56 r.p.m.

ACCIDENT TO MACHINERY OF THE U. S. S. *TEXAS*.

On October 23d the *Texas* held her standardization trials on the mile course at Rockland, Maine, under the supervision of the official trial board. The runs at 10, 12, 15, 17 and 19 knots had been completed as well as the first and second runs at 21 knots. All machinery had functioned well during these runs. At 1:40 P. M., while making the third run at 21 knots, the forward low-pressure valve gear of the port engine broke down completely.

The engines are triple expansion, with two low-pressure cylinders, the sequence from forward being, L.P., H.P., I.P. and L.P. It will thus be noted that the accident was at the extreme forward end of the shaft.

The engine was stopped as quickly as possible but made several revolutions before this could be done. In the meantime the reversing gear had been thrown over to the astern position. Examination then showed conditions to be as indicated on the accompanying sketch.

The injuries in detail were as follows:

(*a*) Both valve stems broken off short in the groove at base of thread, the outboard one snapped short off and the inboard one bent ten or fifteen degrees before breaking.

(*b*) The valve-stem crosshead guide was torn loose from the valve chest, the eight 1-inch studs that secured it having parted. Some of these snapped off short, others broke off after bending slightly and one of them was pulled out, stripping the thread in the valve-chest casting.

(*c*) The valve-stem guide was bent slightly out of true, with the parts pinched together at the bottom.

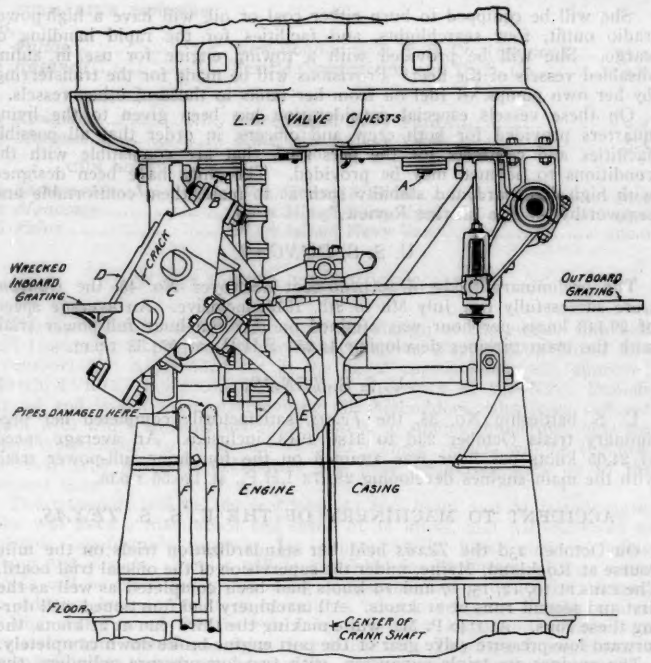
(*d*) The crosshead had a crack about five inches long, extending from the top on the forward side.

(*e*) The link was undamaged except that the distance piece at one end was cracked.

(*f*) The ahead eccentric rod was bent back about 45 degrees in the plane of its own motion.

(*g*) The entire gear was thrown against the water and oil-service pipes on the inboard side, and these, together with the access grating, were damaged.

Examination of the valve chest showed the following injuries:



LOOKING AFT.—UPPER PART OF ENGINE CASING REMOVED.

APPROXIMATE SKETCH OF THE WRECKED F.L.P. VALVE GEAR, PORT ENGINE, U. S. S. "TEXAS," AS IT APPEARED IMMEDIATELY AFTER THE ENGINE WAS STOPPED. THE ACCIDENT OCCURRED WHEN VESSEL WAS MAKING 21 KNOTS, AND THE ENGINE TURNING ABOUT 123 R.P.M.

A—Broken end of outboard valve stem.
B—Broken end of inboard valve stem.
C—Valve-stem crosshead.
D—Valve stem crosshead guide.
E—Ahead eccentric rod.
F—Forced-lubrication pipes.

(*h*) The inboard valve-chest bonnet had one strengthening rib damaged and a piece was broken from the flange through one of the holes for studs securing the bonnet and crosshead guide. This stud was the one that had stripped the thread in the valve-chest casting.

(*i*) The outward valve-chest bonnet was cracked all around inside the rim, the boss having been knocked up into the valve chest.

(*j*) Both valve-stem stuffing boxes were badly damaged, the metal packing rings having been distorted and the glands and bushings badly bent and battered.

(*k*) The inboard valve was found in perfect condition. The outboard valve showed slight chafing at one spot on the upper end and three spots badly chafed and galled on the lower end inboard. The valves have solid wearing rings with followers and had been closely fitted. The galled places indicated the cause of the trouble.

REPAIRS.

After examining the damaged parts the contractor's engineers decided that repairs could be made with such assistance as could be obtained at the engineering establishments in neighboring ports. Accordingly the ship returned to her anchorage at Rockland, using the starboard engine alone. The bent eccentric rod was dispatched to Quincy, Mass., where it was straightened and annealed in the shops of the Fore River Shipbuilding Co., and returned to the ship on the evening of the 25th. A new outboard valve-chest bonnet was cast by the Hyde Windlass Co. at Bath, Me., using the inboard one as a pattern. New glands and bushings for stuffing boxes were also made at Bath, and these parts, machined by the Bath Iron Works, were all on board ready for installation on the morning of the 25th.

The bent crosshead guide was trued up and some studs and small castings were made in a shop in Rockland. All other necessary parts were carried on board, including one spare L.P. valve stem and one spare I.P., which it was necessary to cut to suit. A patch was fitted over the crack in the crosshead.

All parts were on board ready for assembling by 10:00 P. M. of the 25th, and by the afternoon of the 26th they had been completely assembled and the engine tested under steam. The trials were resumed on the morning of the 27th and were carried to completion without further trouble.

The contractors and builders of the *Texas* are the Newport News Shipbuilding and Dry Dock Co., of Newport News, Va. This accident came absolutely without warning and in no way reflects on the ability or alertness of the company's engineering staff.

Chief Engineer Christiansen and his assistants deserve high praise for the untiring skill and excellent judgment shown in making repairs and preparations for resuming the trials.

The weather was fine and clear on the 23d, the day of the accident, but a heavy fog which set in that evening did not lift until three days later. The trial board and its assistants remained on the ship and were able to continue the trials on the first suitable day. The accident is thus seen to have resulted in practically no delay to the trials.

The serious nature of this accident and the facility with which repairs were made in a port almost wholly lacking in the shop equipment necessary for making repairs, illustrates forcibly one of the great advantages of the reciprocating engine. The engine was made ready for any service in three days' time.—U. T. H.

AWARD OF DESTROYER CONTRACTS.

The Secretary of the Navy, on September 16, made conditional award of the contracts for the new torpedo-boat destroyers, *Nos. 57* to *62*, which were provided for in the naval appropriation bill approved March 4, 1913, dependent upon the contractors' acceptance of minor modifications of guaranteed fuel consumption, these modifications being required by the Department in order that greater radius of action desired may be obtained.

The awards are as follows:

One vessel to the Bath Iron Works, at $884,000.00.

One vessel to the Fore River Shipbuilding Corporations, at $861,000.00.

Two vessels to the New York Shipbuilding Company, at $825,000.00. each.

Two vessels to the William Cramp & Sons Ship and Engine Building Company, at $881,000.00 each.

The final design of these vessels was developed by the Bureaus of Construction and Repair and Steam Engineering to produce certain important military characteristics desired by the General Board of the Navy.

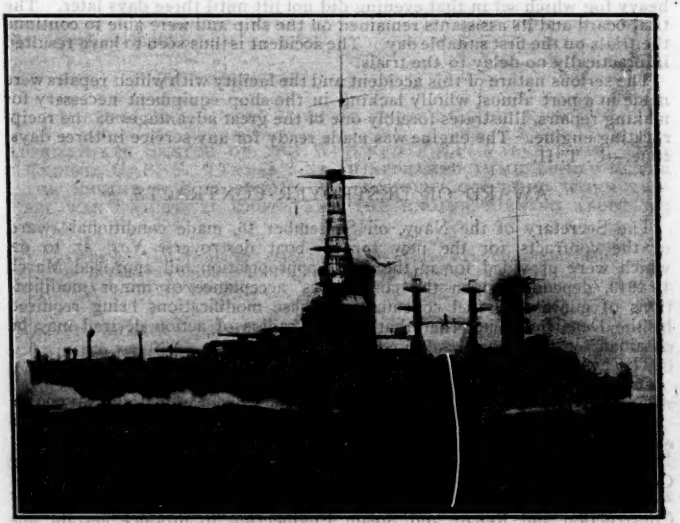
These destroyers are the largest of any of their class yet designed. They will have the same high sustained sea speed as previous boats of

the same class in the United States Navy. They show a decided advance in radius action at a high speed over previous designs, and have largely increased offensive power. A number of changes in types and location of fittings have been made to still further increase their seagoing qualities. Increased space and weight has been assigned for the living accommodations of both crew and officers, in order to provide all possible facilities and comforts for the personnel so that they can remain in the highest state of physical efficiency during long cruises or when performing exacting and hazardous duty with the battle fleet.—"The Navy."

ARGENTINE REPUBLIC.

TRIAL TRIP OF BATTLESHIP *RIVADAVIA.*

The official builders' acceptance trials of the Argentine battleship *Rivadavia,* built by the Fore River Shipbuilding Corporation, Quincy, Mass., were carried out over the Rockland (Me.) measured-mile course. The vessel is 585 feet long, 98 feet beam, designed for a speed of 22½ knots. The trial displacement of the ship is 27,600 tons and the full-load displacment 30,600 tons. The armament consists of twelve 12-inch guns, twelve 6-inch guns and sixteen 4-inch guns. The average of the high-speed runs was slightly over 22.5 knots, the horsepower developed 39,750, and the revolutions 270 per minute. These trials were followed by gun trials, in which it was found that the structural portions of the ship withstood the shock of firing absolutely without injury. Further trials, consisting



Photograph Copyright by N. L. Stebbins.

Argentine Battleship Rivadavia at Full Speed.

of a 30-hour run at 20 knots, a 30-hour run at 15 knots and an 8-hour run at 22.5 knots, will be conducted in the near future. The vessel will be delivered to the Argentine Government early in 1914.—"International Marine Engineering."

CHINA.

CHINESE CRUISER *FEI HUNG*.

The practice cruiser *Fei Hung*, recently completed by the New York Shipbuilding Co., Camden, N. J., for the Chinese government has completed an exhaustive series of speed, gun, and torpedo trials. Guaranteed by her builders to maintain a speed of 20 knots per hour, the *Fei Hung* attained on trial a speed of 22½ knots.

In addition to the full-speed trial, a twenty-four-hour endurance trial was run to determine the fuel consumption at a speed of 18 knots. The results of this test were as satisfactory as those where speed only was a consideration; the consumption of fuel being remarkably low and considerably below that required by the contract.

Upon completion of the full-speed trials all the guns in the ship's armament were severely tested by being repeatedly fired with full battle charges. One broadside or salvo was fired in which all the large guns on board were discharged simultaneously by means of an electric button on the bridge. The unusual test, as well as all the other gun firing, was most satisfactory, and in addition to demonstrating the excellence of the guns gave abundant proof of the strength and ruggedness of the vessel herself.

The gun trials were followed by torpedo tests, upon conclusion of which the *Fei Hung* returned to Camden to be prepared for her long voyage to the East.

The Chinese officers who were present at the trials expressed themselves as greatly pleased with the results obtained and the generally satisfactory performance of the vessel.

The *Fei Hung* is a protected cruiser of about 2,600 tons displacement. She is 320 feet long, has two masts and two funnels. The propelling machinery consists of three steam turbines of the Parsons type which are supplied with steam by three Thornycroft water-tube boilers, one of which is fitted for burning oil fuel. The vessel is constructed with a double bottom and is further divided into watertight compartments by numerous bulkheads, both transverse and longitudinal. A heavy nickel-steel protective deck extends for the whole length, covering engines, boilers, magazines, steering gear and all other vital parts. The ammunition hoists to the largest guns are also protected by nickel-steel trunks; there is a heavy armored conning tower, and the larger guns are provided with armor shields. The armament of the *Fei Hung* consists of two 6-inch, four 4-inch and two 3-inch rapid-fire guns, six 3-pounders, two 1-pounder automatic guns, and two 18-inch torpedo tubes. There is a very complete electric plant, wireless-telegraph outfit, numerous boats, among which are a steam launch and a motor boat.—"The Marine Review."

ENGLAND.

ERRATA.

On page 511 of the August number of the JOURNAL it was stated that the propelling machinery of the new British battle cruiser *Tiger* is to be of the Parsons type and Yarrow boilers. This is an error, as we are informed that the *Tiger* is to be equipped with Curtis steam turbines and Babcock & Wilcox boilers.

BATTLESHIP *QUEEN ELIZABETH.*

The *Queen Elizabeth,* launched at Portsmouth, represents the latest in battleship construction. She will be propelled by turbines solely, and is the first ship fitted to burn oil fuel only under her boilers. Her new 15-inch guns, made by Messrs. Vickers, are described as the most powerful in the world. She has a displacement of 27,500 tons, or 500 tons more than the *Queen Mary,* up to now the largest completed warship afloat. Her turbines are equal to 58,000 H.P., and her speed will be 25 knots. In addition to eight of the big guns, she will carry sixteen 6-inch guns. The 15-inch gun weighs 96 tons, and fires a projectile weighing 1,950 pounds, so that a broadside will mean the discharge of 15,600 pounds of metal. The big guns are mounted in pairs in four turrets on the center line. She is also to carry twelve guns which have been specially designed to meet attacks from airships and aeroplanes, and the upper deck is to be armored as a protection against bombs from above. The funnels are also to be protected against this danger. The decision to use oil to drive the ship has had many consequences. The old bunkers in which the coal was stored have disappeared, and the oil is kept in the double bottom. Then it has been possible greatly to reduce number of stokers, and the *Queen Elizabeth,* notwithstanding her greater power, will have a smaller crew than any previous *Dreadnought.* The estimated cost of the new vessel is £2,350,000, or about £400,000 less than the *Royal Sovereign,* which is to follow her on the building slip. She is the first of the five armored ships of last year's program.—"Page's Engineering Weekly."

BATTLE CRUISER *QUEEN MARY.*

A remarkable speed record is reported to have been made by the *Queen Mary,* the latest of our battle cruisers. It is stated on good authority that this ship attained on her full-power tests a speed of 35.7 knots, or over 41 miles an hour. It is said that the increased length of these vessels has contributed not a little to their speed. The *Indomitable* is 530 feet in length with a beam of 78½ feet, the proportion of the one to the other being 6.75 to 1. In the *Queen Mary* the length is 660 feet and the beam 89 feet, the ratio having been increased to 7.42 to 1. The cost of machinery has not increased to the extent that might have been anticipated, for while the 41,000 H.P. turbines of the *Indomitable* cost £476,481, those of the *Queen Mary* cost only £510,600.—"Page's Engineering Weekly."

THE FIVE BRITISH BATTLESHIPS OF THE 1913–1914 PROGRAM.

The new battleships will differ very noticeably from those of the *Queen Elizabeth* class. They will burn coal, oil being used as an auxiliary in case of necessity; the designed speed will be reduced from 25 to 21 knots, in order to permit of a reduction of 2,000 tons in displacement without affecting in the least the ships' offensive and defensive qualities. The reduction in displacement is obtained principally by a very considerable reduction in beam; and it is hoped that, in comparison with the *Queen Elizabeth* class, the cost of their successors will be lowered by 13 or 14 per cent.—"Le Yacht."

FRANCE.

OFFICIAL TRIALS OF THE BATTLESHIP *COURBET.*

The battleship *Courbet* is a sister ship of the *Jean Bart.* The *Courbet,* however, is fitted with Niclausse water-tube boilers, whereas the *Jean Bart* was fitted with Belleville boilers. The main particulars of the boilers of the *Courbet* are:

Number of boilers	24
Total grate surface	2,035 square feet
Total heating surface	66,306 square feet
Working pressure	256 pounds.
Number of elements	374.
Number of tubes	9,724.
Length of tubes	7 feet 11 inches.
Inside diameter of tubes	3 1/16 and 2 15/16 inches.
Outside diameter of tubes	3 5/16 inches.
Mean diameter of funnels	10 feet.
Height of funnels	65 feet 8 inches.

Preliminary trials of the *Courbet* were started on May 20, after the vessel had been placed in drydock and the hull had been cleaned and painted. The following month the vessel was sent to England with the President of the Republic on board, and the final trials were not carried out until July, and as there was no opportunity to dock the vessel and clean the hull again, the results obtained from the final trials were quite different from those obtained from the earlier trials.

Six-Hour Endurance Trial, May 20.

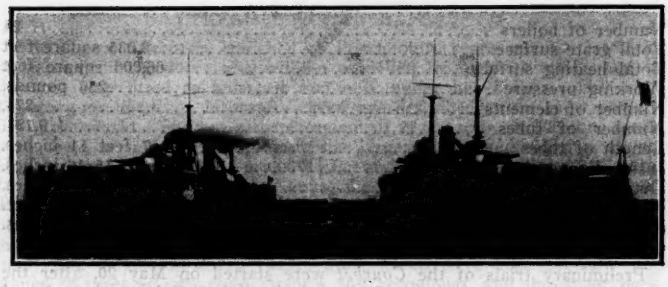
Number of boilers in use	12.
Pressure at steam chest	35 pounds.
Vacuum of condenser	19.2 inches.
Number of revolutions	183.3.
Mean speed	13.1 knots.
Consumption per hour	5 tons, 970 pounds.
mile	901 pounds.

Ten-Hour Full-Speed Trial, May 28.

Boilers in use	24.
Pressure of boilers	249 pounds.
at steam chest	152 pounds.
Vacuum	28.4 inches.
Brake horsepower	25,540.
Revolutions per minute	290.
Mean speed	20.803 knots.
Contract speed	20 knots.
Consumption per hour	23.569 tons.
mile	2,495 pounds.
at 20 knots, as per contract	2,646 pounds.

Twenty-Four-Hour Trial, July 1 and 2.

Boilers in use	22.
Pressure at boilers	229 pounds.
steam chest	87 pounds.
Vacuum	28.84 inches.
Revolutions per minute	256.
Mean speed	18.078 knots.
Total consumption per hour	13.495 tons.
Consumption per mile	1,660 pounds.
as per contract	1,808 pounds.



TWO VIEWS OF THE FRENCH BATTLESHIP "COURBET" TAKEN AT THE TIME OF HER OFFICIAL TRIALS.

Three-Hour Full-Steam Forced-Draft Trial, July 9.

Boilers in use	24.
Pressure at boilers	238 pounds.
steam chest	169 pounds.
Vacuum	27.60 inches.
Revolutions per minute	296.
Mean speed	20.737 knots.
Total consumption per hour	29.562 tons.
Contract consumption per square foot of grate at 20-knot speed	32.8 pounds.
Consumption on trial at 20.737 knots	32 pounds.
Consumption per mile, as per contract, for 20-knot speed	3,384 pounds.
Consumption per mile on trial for 20.737-knot speed	3,157 pounds.
Air pressure in boiler rooms	0.88 inch of water.

Six-Hour Endurance Trial, July 16.

Boilers in use	6.
Pressure at steam chest	26 pounds.
Vacuum	30 inches.
Revolutions per minute	127.
Speed	9.396 knots.
Total consumption per hour	3.149 tons.
Consumption per mile	740 pounds.
as per contract	750 pounds.

—"International Marine Engineering."

NEW BATTLESHIP *VENDÉE*.

The new French battleship *Vendée*, which is to be laid down on January 1, 1914, will be a close second to the United States ship *Pennsylvania* for the title of the most powerful ship in the world. The *Vendée* will have three quadruple turrets, mounting 13.4-inch guns, while the *Pennsylvania* mounts the same number of 14-inch weapons. Speaking about the construction of the *Vendée*, Chief Constructor Doyère says "success will come to the party possessing the most powerful guns together with the most efficient firing and telescopic appliances, and who is in a position to secure the benefits of the first blows." It has become a well-known fact that the French Admiralty is preparing modified copies of British *Warspites*, but with less speed and heavier guns, 15-inch being named as the size of the guns with which they are equipped. From the present outlook it appears that during 1914 France will easily maintain her superiority over the Austro-Italian combination.—"The Navy."

GERMANY.

SHIPBUILDING PROGRESS.

The four armored ships of the 1911 program have been launched since January. The battleship known as "S" took the water on March 1 from the Imperial dockyard at Wilhelmshaven, and was named the *König*. The "Ersatz-Kurfürst Friedrich Wilhelm" was launched on May 5 from the Vulkan yard at Hamburg and named the *Grosser-Kurfürst*. The "Ersatz-Weissenburg" was put afloat on June 4 at the Weser yard, Bremen, and named the *Markgraf;* and the battle cruiser "K," built at the yard of Messrs. Blohm and Voss, Hamburg, after an unsuccessful attempt at launching on June 14, eventually took the water on July 1, when she was named the *Derfflinger*. The armament of the three battleships is understood to include ten 14-inch guns, fourteen 6-inch and twelve 3.4-inch guns, and their displacement is stated to be about 26,500 tons. No authentic information about them, nor about the battle cruiser, was published on the occasion of the launches. These four vessels increase the total of German Dreadnoughts afloat to twenty-one, of which sixteen are battleships and five battle cruisers. The *Kaiserin* and *Seydiltz*, of the 1910 program, were undergoing trials in May.—"Journal of the Royal United Service Institution."

RECENT ACQUISITIONS.

The new German torpedo boats *S-13* to *S-24*, built by Schichau, have shown wonderful speed in their trial runs. "The Schiffbau" makes the statement that *S-22* maintained a mean speed of 34.18 knots on her three-hours' acceptance trial at Pillau on July 19, while her velocity on a measured mile was 34.91 knots. The *S-22* is a boat displacing only 564 metric tons. To foreigners one of the peculiarities attending the trials is that it is not definitely known whether *S-22* and her sister boats are oil-fired boats or not, but it is rumored that they are.

The small cruisers *Karlsruhe* and *Rostock* are both ready for trial. The cruiser of the 1912 program, *Ersatz Prinzess Wilhelm* and the *Ersatz Irene*, are nearly ready for launching. The first is being built at the yard at Kiel, and the second at the Weser yard.

The intense popular interest of the Germans in air craft is shown in the interest in the naval airship M. L. 1. This airship has made repeated visits to every part of the Baltic and the North Sea coasts and over most of the harbors of the North Sea territory and the exercise grounds of the High Sea fleet north of Heligoland. The M. L. 1 can reach a height of more than 6,000 feet and remain 40 hours in the air. She is equipped with a wireless apparatus capable of sending messages 312 miles, and can observe the approach of an enemy's force at a great distance. She possesses real strategic value as an air cruiser in war times. Two more sister airships are being built.

The Germans feel assured that hostile fleets can be kept under constant observation by means of these airships.—"The Navy."

GREECE.

BATTLESHIP *SALAMIS*.

The Greeks have a new battleship under way, the construction of which is in sharp contrast to that of the *Reshad V*. The ship referred to is the *Salamis*, a battle cruiser of 19,000 tons, carrying eight 14-inch guns, with a sea speed of 23 miles. The cost of the Greek *Salamis* is nearly three-

quarter million pounds sterling less than that of the *Reshad V.* The *Salamis* represents the ideas of the advanced constructors, who favor high speed and powerful armament rather than a low speed with heavy defensive armor.—"The Navy."

ITALY.

TRIPLE-GUN TURRETS.

Both triple and twin turrets figure in the design of the *Dandolo* and *Morosini*, laid down in December, 1912, by the firms of Ansaldo and Odero, in which Messrs. Armstrong, Whitworth & Co., and Messrs. Vickers, Ltd., are respectively interested. Each vessel will carry ten 14-inch guns, arranged in two triple and two twin turrets on the keel line. In the next battleships laid down, however, it is stated that the triple-turret method will not be followed. According to a dispatch from the Rome correspondent of the "New York Herald" (European Edition), published on June 15, the Italian Admiralty, which initiated the triple-gun turret for the *Dante Alighieri* in 1909, has now definitely abandoned it, and the four battleships laid down this year will have only two big guns mounted in each turret. The same writer states that firing practice with the *Dante Alighieri's* guns showed that when two contiguous guns were fired in a triple-gun turret the turret was often put out of working order. It has been decided that the four new ships, which are to be completed in 1916, will be of 30,000 tons displacement, 25 knots speed, and will carry eight 15-inch and twenty 6-inch guns, with a maximum thickness of 12 inches of armor.—"Journal of the Royal United Service Institution."

TRIALS OF THE *NINO BIXIO.*

Two trials have been lately made with the new type of Italian "Scout" *Nino Bixio.* The first of these, which was intended to consist of twenty-four hours' continuous steaming, would have been a particularly severe one, since 15,000 horsepower, or about two-thirds of the full power, would have had to be developed working with the two wing turbines only. The two engines would therefore have to be kept up to a mean of fifteen-sixteenths of their full power for twenty-four hours on a stretch. This test began well. The boilers gave ample steam with little more than 1¼ inches of air pressure, while the turbines developed the 15,000 horsepower required and the vessel maintained the estimated speed of 25 knots. The trial was, however, suspended after twelve hours' running in consequence of a small mishap to the feed-water heaters.

The second test of six hours at full speed, with the thirteen boilers and three turbines all working, took place off Naples on October 18th. The engines, which are divided into three independent groups, surpassed the contracted horsepower of 22,500, developing 24,000 horsepower and giving a speed of 28 knots for a reported coal consumption of 1 pound per horsepower. The mean number of revolutions was 430 and the maximum boiler pressure 19 kilos. per square centimeter—270.24 pounds to the square inch.

The results are considered satisfactory in every respect, both from the point of view of the engines and from that of the seagoing qualities of the vessel.—"The Engineer."

JAPAN.

JAPANESE NAVAL ARTILLERY.

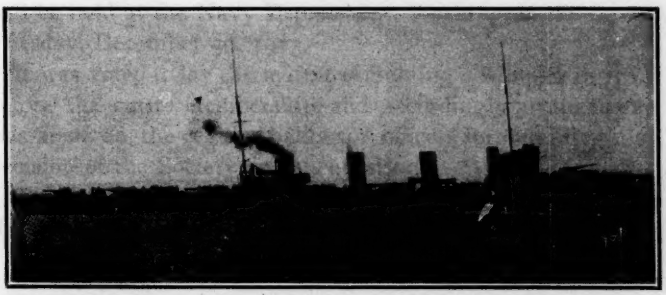
It seems to be corroborated that twenty-eight 14-inch pieces have been ordered of Vickers for the battle cruisers of the *Kongo* class. The other pieces are being manufactured in Japan at the Muroran gun factory, which is equipped for building 15-inch and 16-inch guns, though guns of such large caliber have not yet been built there. The management of the shops, expecting to be able to get along without the assistance of the English experts, had retained only a small number of them, following therein the practice which had obtained in Japan for a long time—that is, of dispensing, as far as possible, with the help of foreigners. But in the face of the disturbing number of articles rejected on account of bad workmanship (more than half, it is said), it has just been decided to have engineers and foremen again come from England in such number as to raise the European personnel to forty.

The three new battleships which have just been ordered will probably carry 15-inch guns. There is also talk of making a 14.5-inch caliber.—"Revue Maritime."

RUSSIA.

TORPEDO BOAT DESTROYER *NOVIK*.

The world's fastest seagoing vessel has recently performed its trial runs. According to German press notices, the Russian torpedo-destroyer *Novik*, built in the shipyards of Messrs. Vulcan-Werke, in connection with the official trial on the measured mile, with her trial load, has reached a mean speed of 37 knots, the maximum speed being 37.3 knots per hour. Some days afterward the vessel underwent the continuous six-hours' trial provided by contract. The speed prescribed for the trial, viz: 36 knots, was not only reached, but exceeded considerably, a mean speed of 36.2 knots, throughout the six hours, and a mean speed of 36.8 knots



Length, 326.9 feet; Beam, 31.4 feet; Draught, 10 feet; Displacement, 1,280 tons; Effective horsepower, 36,500; Mean speed on six-hour trial, 36.2 knots; Mean speed on measured mile, 37 knots.

RUSSIAN 37-KNOT DESTROYER "NOVIK," THE FASTEST SEA-GOING VESSEL AFLOAT.

during the last three hours being obtained. The engines and boilers, in spite of these high speeds, never were pushed to the limits of their capacity, and no smoke issued from the funnels of the boilers, which were fired exclusively with liquid fuel.

The *Novik* is a turbine-propelled vessel. The following gives some of her main data:

Length between perpendiculars, feet	326.9
Maximum breadth, feet	31.4
Displacement, tons	1,280
Draught, feet	10
Engine output, eff. horsepower	36,500
Contract speed, knots	36
Crew, men	140

The *Novik* mounts four 4-inch rapid-fire guns and four torpedo-tube sets. She is the only vessel of her class; but Russia is building eight destroyers of 1,050 tons and 34 knots speed.—"Scientific American."

ASSOCIATION NOTES.

The regular annual meeting of the Society was held in Washington, D. C., on Tuesday, October 7, 1913. The following were nominated for officers for 1914:

For President:

Rear Admiral John R. Edwards, U. S. N.

For Secretary-Treasurer:

Lieutenant Commander H. C. Dinger, U. S. N.

For Members of Council (three to be voted for):

Engineer-in-Chief R. S. Griffin, U. S. N.
Engineer-in-Chief C. A. McAllister, U. S. R. C. S.
Captain B. C. Bryan, U. S. N.
Captain Emil Theiss, U. S. N.
Commander S. S. Robison, U. S. N.
Commander U. T. Holmes, U. S. N.
Naval Constructor John Q. Walton, U. S. R. C. S.
Lieutenant R. C. Davis, U. S. N.
Lieutenant George B. Wright, U. S. N.

Engineer-in-Chief C. A. McAllister, U. S. R. C. S., later withdrew his name.

The annual meeting of the Society for the counting of votes will be held at the Navy Department, Washington, D. C., on Tuesday, December 30, 1913.

It was voted to lay the matter of holding a banquet in 1914 before the entire membership, and accordingly arrangement was made on the regular ballot for officers for obtaining the decision of the Society on this question.

The following new members have joined the Society since the publication of the last JOURNAL:

MEMBER.

Lieutenant Harold G. Bowen, U. S. N.

ASSOCIATE.

Dr. A. Rateau, Paris, France.

The American Society of Civil Engineers
The American Institute of Mining Engineers
The American Society of Mechanical Engineers
The American Institute of Electrical Engineers
and
The Society of Naval Architects and Marine Engineers
extend to the officers and members of
American Society of Naval Engineers
a most cordial invitation
to attend and to participate in the proceedings of
The International Engineering Congress
to be held in connection with
The Panama-Pacific International Exposition
September twentieth to twenty fifth
in the year one thousand nine hundred and fifteen
in San Francisco
California

In connection with the Panama-Pacific International Exposition which will be held in San Francisco in 1915, there will be an International Engineering Congress, in which engineers throughout the world will be invited to participate.

The congress is to be conducted under the auspices of the following five National Engineering Societies: American Society of Civil Engineers, American Institute of Mining Engineers, The American Society of Mechanical Engineers, American Institute of Electrical Engineers, and The Society of Naval Architects and Marine Engineers.

These societies, acting in coöperation, have appointed a

permanent Committee of Management, consisting of the Presidents and Secretaries of each of these societies, and eighteen members resident in San Francisco.

The Committee has effected a permanent organization, with Prof. Wm. F. Durand as Chairman, and W. A. Cattell as Secretary-Treasurer, and has established executive offices in the Foxcroft Building, 68 Post Street, San Francisco.

The ten members of the Committee, consisting of the Presidents and Secretaries of the five national societies, will constitute a Committee on participation, through whom all invitations to participate in the Congress will be issued to governments, engineering societies and individuals.

The papers presented at the Congress will naturally be divided into groups or sections. During the Congress each section will hold independent sessions, which will be presided over by a chairman eminent in the branches of engineering covered by his section.

The scope of the Congress has not as yet been definitely determined, but it is hoped to make it widely representative of the best engineering practice throughout the world, and it is intended that the papers, discussions and proceedings shall constitute an adequate review of the progress made during the past decade and an authoritative presentation of the latest developments and most approved practices in the various branches of engineering work.

The papers, which will be collected and published by the Congress, should form an invaluable engineering library, and it is intended that this publication shall be in such form and at such cost as to become available to the greatest possible number.

Membership fees are five dollars, and information in regard to the Congress may be obtained by addressing the Secretary-Treasurer at the address given above.